

Historic, Archive Document

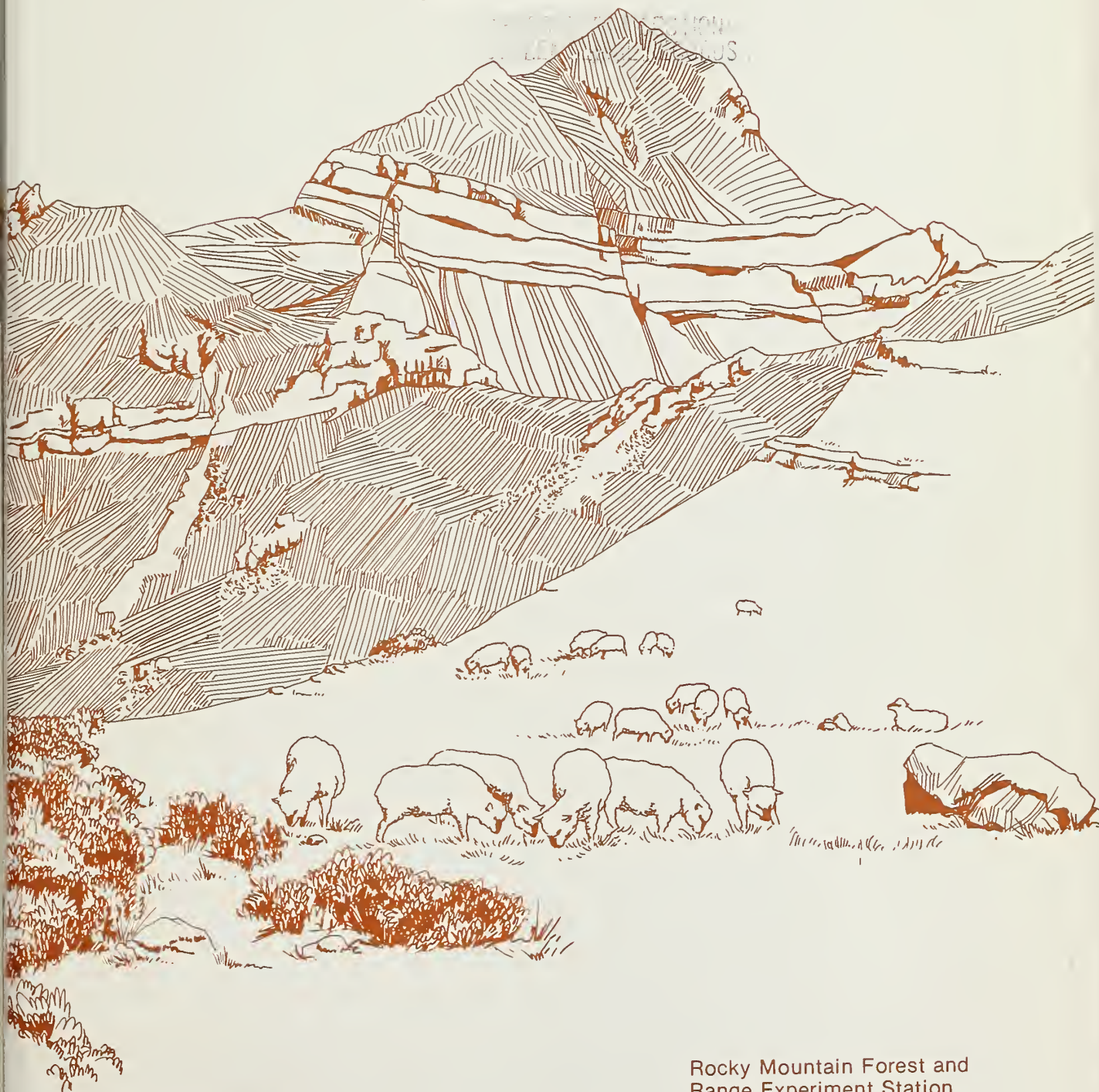
Do not assume content reflects current scientific knowledge, policies, or practices.

A99.9
76324

Alpine Range Management In The Western United States Principles, Practices, And Problems:

The Status of Our Knowledge

John F. Thilenius



USDA Forest Service
Research Paper RM-157
November 1975

Rocky Mountain Forest and
Range Experiment Station
Forest Service
U.S. Department of Agriculture
Fort Collins, Colorado 80521

Abstract

Thilenius, John F.

1975. Alpine range management in the western United States—principles, practices, and problems: The status of our knowledge. USDA For. Serv. Res. Pap. RM-157, 32 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521

Reviews the present knowledge on the ecology and management of the alpine zone in western North America; describes the characteristics of the alpine; covers the unique ecology of the high-elevation, cold-dominated, alpine ecosystems; and discusses their management, with emphasis on the range resource and its relationship with other uses.

Keywords: Alpine ecosystem, alpine range management.

2007
ALPINE RANGE MANAGEMENT IN THE WESTERN UNITED STATES— —
PRINCIPLES, PRACTICES, AND PROBLEMS: =
The Status of Our Knowledge //

John F. Thilenius, Principal Plant Ecologist
Rocky Mountain Forest and Range Experiment Station¹

¹Central headquarters is maintained at Fort Collins, in cooperation with Colorado State University; research reported here was conducted at the Station's Research Work Unit at Laramie, in cooperation with the University of Wyoming.

Contents

	Page
INTRODUCTION	1
THE ALPINE ZONE	1
Definition	1
Geographic Distribution	1
Altitudinal Limits	2
Macro Land Forms	2
Micro Land Forms	3
Soils	3
Climate Regime	5
Moisture	5
Wind	7
Radiation	8
Temperature	8
Floristics	9
Animals	9
ALPINE ECOLOGY	10
Adaptations of Plants to the Environment	10
Growth and Development	10
Biomass and Productivity	11
Phytosociology	12
RANGE MANAGEMENT IN THE ALPINE ZONE	14
Domestic Livestock Grazing	15
Grazing Systems	15
Range Readiness	17
Quantity and Quality	17
Preference and Utilization	18
Range Condition and Trend	20
Range Improvement	22
Integration with Other Uses	23
Watershed	23
Wildlife	24
Recreation	26
Mining	27
SUMMARY AND CONCLUSIONS	28
LITERATURE CITED	29

ALPINE RANGE MANAGEMENT IN THE WESTERN UNITED STATES— PRINCIPLES, PRACTICES, AND PROBLEMS: The Status of Our Knowledge

John F. Thilenius

INTRODUCTION

Because of the steep, rugged topography, high erosion potential of the soils, and the short growing season, alpine ranges present special management problems. Basic knowledge of their ecology is therefore prerequisite for managers to properly allocate the various resources of the alpine zone. The first portion of this Paper characterizes the zone; the second reviews the present status of our knowledge of the ecology of the alpine area; followed by the management of the ecosystem, with emphasis on the use of the forage resource.

THE ALPINE ZONE

Definition

Alpine ecosystems occupy those mountain areas above timberline that are characterized by short, cool growing seasons and long, cold winters. The vegetation is characteristically dominated by low-growing (ca. 20 cm or less), perennial, herbaceous, and shrubby vascular plants; extensive mats of cryptogams (mosses, lichens, etc.); and the almost complete absence of trees (fig. 1).

Geographic Distribution

In western North America, alpine ecosystems extend from the Arctic southward along the Rocky Mountains and Cascade-Sierra Nevadas. In the con-



Figure 1.—Alpine rangeland in the Absaroka Mountains of northwestern Wyoming.

terminous United States, the Rocky Mountain segment is found on the highest portions of the mountain ranges between the Great Plains and the Great Basin, from Montana southward to the Sangre de Cristo Mountains of New Mexico. Outliers occur on San Francisco Peak in Arizona (Little 1941), and on the summits of the higher peaks in the desert ranges of the Great Basin (Loope 1969).

Alpine ecosystems are poorly developed in the Cascade Range of the Pacific Northwest, where much of the zone above timberline is occupied by glaciers, snowfields, and bare rock (Franklin and Dyrness 1973). The Sierra Nevada alpine zone is more extensive, and extends south to the San Jacinto Mountains of southern California.

There are also limited areas of alpine tundra on the highest summits of the mountains in the New England region of the eastern United States (Bliss 1963).

Altitudinal Limits

Timberline, which defines the lower limit of the alpine zone, is that elevation above which erect trees do not normally grow. Timberline varies with local environment, and is more of a zone than a distinct line. In the Rocky Mountains it is located at about 3600 m in northern New Mexico (Schwan and Costello 1951), 3350 m in northern Colorado (Marr 1964), 3000 m in northern Wyoming (Johnson and

Billings 1962), and as low as 2200 m in northern Montana (Choate and Habeck 1967). Alpine-like vegetation is present at 1600 m in the Olympic Mountains of Washington (Kuramoto and Bliss 1970) and in New England (Bliss 1963), but Krummholz (prostrate wind-sculpted trees) occurs above 3600 m in the central Sierra Nevada Mountains (Klikoff 1965). The general decrease in the elevation of timberline with latitude is about 100 m per degree north.

Macro Land Forms

Because the alpine zone is present only on mountains, much of the landscape is rugged and broken, with rocky, snowcapped peaks, spectacular cliffs, and talus slopes (fig. 2). However, there are also many large areas of gently rolling to almost flat topography (fig. 3). The character of any one area depends to a great extent on the degree and type of glaciation. Valley glaciers have been a major factor in the formation of the landscape of the rugged and spectacular alpine regions, and cirques, hanging valleys, and morainal deposits are common features of the landscape. The major valleys in these regions have the broad U-shaped cross section and stepwise longitudinal section of glacial valleys, and terminate in cirques. Flat to rolling terrain may be the result of smoothing by glacial action or **cryoplanation** (leveling by frost action) in areas which were unglaciated.



Figure 2.—Rugged alpine landscape in the Wind River Mountains, Wyoming.



Figure 3.—Level to rolling alpine landscape in the Absaroka Mountains, east of Yellowstone Park, Wyoming.

Micro Land Forms

Even in areas of well-vegetated, gentle topography there is a considerable amount of bare rock and soil. Although some may be caused by human mismanagement, much of it is due to the natural processes of **conglifraction** (splitting of rock by frost action) and **congliturbation** (stirring, thrusting, heaving, and sorting by frost activity). The result of these **cryopedogenic** processes is many kinds of patterned ground.

Also present as natural phenomena are lobed masses of soil (**solifluction terraces**) or rock (**rock terraces**) which move downhill as the result of viscous downslope flow of saturated soil (**solifluction**) or the downslope displacement of material in response to alternate freezing and thawing (**frost creep**). Either will move at the rate of 3 to 4 cm a year, and buried soils are common beneath them (Benedict 1970).

In many otherwise well-vegetated alpine zones, long narrow lines of rock running downslope are a prominent landscape feature. These **rock streams** appear to be caused more by water erosion than cryopedogenic action, since a small erosion fan is usually present at the base of the slope (Retzer 1962) (fig. 4).

Erosion features (fig. 5) are natural in the alpine, and it is necessary to be able to distinguish between them and man-caused deterioration to fully interpret the results of management.

Soils

Alpine soils range from shallow, rocky, and gravelly lithosols with little or no petrogenic development to boggy, organically derived peats. Mineral soils on well-drained areas with a good vegetative cover generally show considerable pedogenic development. The usual sequum (horizon sequence) is $O_2/A_1/B_2/C$. There is a high concentration of organic matter in the upper (O_2 and A) horizons, but little evidence of eluviation of clay or chemical leaching in the lower horizons.

Mineral soils in areas of restricted drainage usually have an $O_2/A_1/C$ sequence. The organic content is greater than that of the well-drained soils, but not peaty. They may have permafrost underlying them.

Organic soils develop in areas where water is ponded for long periods. The surface layer of peat may overlie water-deposited mineral material. Permafrost is usually present at relatively shallow depths.

Under the current soil classification system (Soil Survey Staff 1970), the rocky lithosolic soils would be classified at the Great Group level as **Cryorthents**. The more fully developed soils with either the $O_2/A_1/B_2/C$ or $O_2/A_1/C$ sequum would be classified as **Cryochrepts**, **Cryumbrepts**, or **Cryoborolls**, depending upon the kind of epipedon (surface horizon) present and the degree of development. The peaty soils would be called **Cryofibrists**, **Cryo-**



Figure 4.—Natural rock streams in the alpine zone of the Absaroka Mountains, Wyoming.



Figure 5.—Active natural erosion features on alpine rangeland in northwestern Wyoming.

saprists, or Cryohemists depending on the degree of decomposition of the organic material from which they were derived.

Alpine soils are in general much less uniform than the soils of lower elevation areas. Part of this is due to the variability of mountain terrain and geology, and part to cryopedogenic processes which result in a rather dynamic and unstable soil surface.

Because they are of limited extent, not arable, and generally inaccessible, little work has been done on the fertility of alpine soils of the western United States. The general consensus is that alpine soils have low inherent fertility. Low fertility may result in part from the type of parent rock from which they are formed: soils from granites are inherently less fertile than those from volcanic rocks or limestone.

Low levels of nitrogen have been considered as limiting alpine plant growth. The problem is not one of low total nitrogen content, because the surface horizons contain abundant nitrogen (ca. 20,000 to 40,000 kg/ha) in the organic form. However, there is very little (less than 0.01 percent) inorganic nitrogen as nitrate or ammonium, the form in which it is available for plant growth. The relatively low level of inorganic nitrogen is probably due to the low microbial activity of alpine soils, which is in turn a result of low soil temperatures. Psychrophilic bacteria that grow at temperatures approaching 0°C may be of major ecological importance in the nitrogen relationships of alpine soils (Faust and Nimlos 1968).

With such low levels of nitrogen, a rapid response would be expected to small amounts of nitrogen fertilizer. This has not been the case, however: up to 270 kg of NH_4NO_3 were required per ha before a plant response was noted in a study done in the alpine zone of Colorado (Faust and Nimlos 1968). Similar results were reported in the alpine zone of southeastern Wyoming (Scott and Billings 1964).

While nitrogen may limit alpine plant growth, other soil nutrients seem to be present in fairly adequate amounts (Bliss 1960). However, Smith (1966) in a greenhouse study of alpine soils using oat as an indicator plant, found a strong response to phosphorus, but no response to potassium or micronutrients. Scott and Billings (1964), on the other hand, could not show any response to phosphorus fertilization in soils collected in the same area. In their tests, however, they used alpine species (*Deschampsia caespitosa* and *Festuca ovina*) rather than oat. The problem of alpine plant-soil fertility relationships remains to be clarified.

Climate Regime

Moisture

The most important factor controlling the distribution and growth of alpine plants is soil moisture (Billings and Mooney 1968). Soil moisture, in turn, depends to a large extent on the drift patterns of the snow that result from the interaction between wind and topography (figs. 6, 7).



Figure 6.—Winter snow cover in the alpine zone, Nipple Mesa, Absaroka Mountains, Wyoming.



Figure 7.—Late-lying snowbanks on lee slopes are a common landscape feature of alpine rangelands well into July.

The most severe alpine environments are of two general types: (1) windswept dry ridges, and (2) late-lying snowbanks. Plants are absent in the most extreme of either of these sites. In the former, drought conditions exist both winter and summer. In the winter, strong winds remove most of the snow that falls, and water is in the form of ice; in summer, winds increase evapotranspiration rates. Plants buried under the snow have some protection from wind and abrasion, but because the water is frozen, it is unavailable to them.

Plant growth begins in most alpine species as soon as the snow melts. A few species may start growth under a thin cover of snow if free water is available at the snow-soil interface. Late release dates provide too short a growing season for good plant development, and floristic vegetational differences are obvious along a gradient from areas released from snow in the early part of the season to the areas uncovered later (Billings and Bliss 1959). Soil drought is accentuated at these later dates because of a relative lack of melt water and relatively high evapotranspiration.

Since the absence of plant development also influences soil development, soils underlying late-lying snowbanks are also poorly developed and often low in humus; hence they are also low in water-holding capacity which accentuates the drought-stress conditions.

The daily cycle of melt water from the snowbank is rather unique. It amounts to periodic irriga-

tion, as water is released mainly during daylight hours after air temperatures rise above the freezing point. Large amounts of water flow from the lower edge of the snowbank, often as a sheet rather than in definite watercourses, and the soil and plants may be submerged for several hours during the daytime. Night temperatures are usually below freezing, with a resultant lowering or often complete cessation of flow. The generally well-drained nature of alpine soils, especially those on steeper slopes, allows the water to drain away during the night. Soil aeration improves and remains at a good level until the return of the water during the subsequent day. Thus, the soils lying below the snowbank are subjected to alternating periods of saturation and aeration; plants occupying these sites must be adapted to this situation.

Precipitation during the growing season may have little effect on the growth rate of alpine species. It often comes in high-intensity rainstorms with consequent high runoff and lack of penetration into the root zone. The degree of vegetative cover may also influence the rate of infiltration. Dense turf may preclude water reaching the soil, and in many alpine areas the cryptogam layer may effectively seal the surface of areas not covered by vascular plants. Because winds are generally strong throughout the year, water held on top of vegetation will be rapidly evaporated. On the other hand, active cryopedogenic features, with much exposed and loosely arranged bare rock, allow moisture to

reach into the soil, but unless lateral drainage occurs this water will not be available for plant growth.

Water erosion is evident in the alpine zone. The effect of water in producing rock streams has already been discussed. Rill and gully erosion is common below late-lying snowbanks, especially those on steep slopes. This type of erosion is present in areas that have not been subjected to livestock grazing and is probably a natural process, although the rate of such erosion may be increased by mismanagement.

Sheet erosion occurs below late-lying snowbanks where melt water may flow over the entire soil surface rather than in a narrow watercourse. Such erosion contributes to the existence and size of nivation cirques (Retzer 1962).

Wind

The alpine zone is seldom calm. Average wind-speeds of 40-50 km/hr are common during the winter, and speeds exceeding 160 km/hr (ca. 100 mi/hr) are not a rarity. Summer winds usually are not as strong, but may exceed 10 km/hr on a weekly basis and be as high as 30-35 km/hr/wk. Although windspeed is reduced near the ground, the low stature and sparse cover of vegetation on many alpine sites allows the wind to be more effective than in a taller, layered vegetation.

The effects of wind are many and varied. Wind directly influences the moisture pattern of the alpine zone by moving snow from areas where it falls to lee slopes or otherwise protected sites. The low stature of most alpine vegetation may be partially a direct influence of wind through mechanical abrasion from blowing ice, snow, and soil particles. Wind effectively reduces air and leaf temperatures and influences transpiration rates. Bliss (1960) reported that transpiration rates for tundra shrubs are directly related to windspeeds below 9.7 km/hr but inversely related to speeds above that rate, probably due to complete closure of stomata. Wind also influences pollination both directly in wind-pollinated plant species and indirectly as it affects the activities of pollinating insects. Its role in seed dissemination is obvious.

Wind-eroded land is common in alpine regions. Generally, the affected areas are found along ridgetops at the heads of valleys and in high, exposed locations (fig. 8). Areas of wind erosion are generally elongated parallel to the ridgeline and may be many meters wide. Fine soil particles are removed by the wind, leaving only the coarser sands, gravel, and rock. As this layer thickens, it acts as a mulch and retards or stops further removal of material by the wind. The eroding belts appear to widen downslope by undercutting the turf. Plants are killed both by mechanical abrasion of wind-driven particles and by desiccation within the exposed root zone. The



Figure 8.—Wind-eroded ridge in the alpine zone, Wind River Mountains, Wyoming.

pattern of wind erosion is generally uni-directional and dependent upon the prevailing direction of the winds. Partially because of this, plant recolonization of wind-eroded areas is slow because propagules are blown away from the area.

Wind erosion may not be completely detrimental. Soil particles removed from one area are caught by vegetation or otherwise deposited in other areas. Because these particles are primarily the clay and silt fraction, they can add to soil depth, fertility, and water-holding capacity (Rétzer 1962).

Radiation

Solar radiation affects soil and air temperatures, humidity, soil moisture, and the energy flow within the alpine ecosystem. Because of their high elevation, alpine areas receive intense solar radiation on clear days during the growing season. Values exceeding 700 langleys/24 hr (1 langley = 1.0 g-cal/cm²) have been measured, but the average value is in the range of 300 to 500 langleys because of cloudiness. On very cloudy days, values may be less than 100 langleys/24 hr even in midsummer.

Due to orographic lifting, clouds are the rule rather than the exception in the alpine zone. The general daytime growing-season cloud pattern is: Clear mornings (to ca. 1200 hr); scattered to broken cloudiness in the afternoon, often with thunderstorms; and partial clearing toward sunset.

The length of photoperiod in midlatitude alpine areas does not exceed 16 hr, and this may be effectively reduced by local topography. Because of differences in day length, the rate of incoming solar radiation in the alpine at midlatitudes is about twice that received in the Arctic, although total incoming solar radiation values during the summer are about equal (Bliss 1962).

The intensity of ultraviolet solar radiation on an alpine environment is not greatly different from that at lower elevations in the same region, although some difference can be expected from the thinner atmosphere and general lack of atmospheric pollutants of the alpine zone. Controlled experiments by Caldwell (1968) showed little or no indication of change in plant growth or development when ultraviolet light was excluded from a natural alpine community. Under controlled laboratory conditions, however, ultraviolet light alone produced minor damage to some alpine species.

An unknown factor in high-elevation alpine ecosystems is the effect of cosmic radiation on the plants. However, mountain areas receiving high-intensity cosmic radiation are usually above the normal elevation limits of most alpine species.

Temperature

The overriding environmental attribute of the alpine zone is cold temperature. The mean growing-season air temperature is often at or near 0°C. According to Warren Wilson (1957), low temperatures affect plant growth in two ways:

- (1) they are near the lower cardinal point for many metabolic processes;
- (2) acceleration of metabolic processes is greater at low temperatures.

The temperature regime in the alpine zone is highly variable. Not only are there pronounced shady-slope-sunny-slope variations caused by macrotopography, but also important variation is caused by microtopography. A few centimeters change in elevation caused by a hummock or depression can cause a change of several degrees, and a rock or tussock may have a distinct north-slope-south-slope temperature regime.

While the air temperature at 1 m or more above the ground may be cold, temperatures in the micro-environment at or near the ground surface may be relatively warm. This of course varies with the coverage of the plant community, angle of incidence of incoming solar radiation, nature and color of the ground surface, wind, soil moisture, and other factors. Since most alpine plants rarely exceed 20 cm in height they are adapted to take advantage of these warmer temperatures near the ground. Furthermore, because of their physiognomy, color, and inherent temperature-heat balance, the alpine plant itself possesses a **phytomicroclimate** where the temperature may be several degrees warmer than that in the immediate environment.

Temperatures in different parts of a given plant may also vary by several degrees. For example, the temperature inside a white-colored flower may exceed that of the surrounding air by 0.7°C to 2.0°C, while lilac-colored flowers have temperatures 3.4°C to 4.2°C warmer than the surrounding air (Bliss 1966).

Alpine plants not only have adapted to take advantage of the warmer microclimatic regime near the soil surface, but also have the ability to withstand sudden depressions in temperature to below freezing. Relatively high osmotic concentrations of the plant fluids may be a factor in preventing freezing damage (Bliss 1966).

High growing-season temperature may be more limiting to the distribution of alpine vegetation than low temperatures. Under high temperature regimes, carbohydrate reserves are depleted more rapidly than at low temperatures because rates of photosynthesis are lower at high temperatures (Bliss 1962).

Respiration rates do not seem to be as affected by temperature and, in fact, the dark respiration rate of alpine species is higher at all temperatures than that of lowland plants.

Floristics

The flora of the alpine areas of western North America has strong similarities to that of the Arctic and European Alps. The Rocky Mountain alpine flora appears to be more closely similar to that of the Arctic than does the flora of the Cascade-Sierra Nevada Mountains. The Sierran alpine flora is particularly unique in that it contains a relatively large number of annuals, and has very strong floristic relationships with the desert floras of the Great Basin to the east and California flora to the west (Chabot and Billings 1972).

Compared to floras of low elevations, the alpine flora is species-poor. Usually there are no more than 200 to 300 species present in the alpine zone of a given mountain range, and many of these are common to most alpine areas. Members of the grass (Poaceae) and sedge (Cyperaceae) families are almost ubiquitous in alpine areas. Additional families with wide alpine distribution are the saxifrage (Saxifragaceae), rose (Rosaceae), mustard (Brassicaceae), buckwheat (Polygonaceae), and pink (Caryophyllaceae). Many of the shrubby species are members of the willow (Salicaceae) and heath (Ericaceae) families.

Animals

While often not easily seen, wild animals are relatively abundant in the alpine zone. Many mammals utilize the alpine ranges for summer habitat. Others may be resident throughout the year, although yearlong residents usually occur also at lower elevations.

Among the common yearlong resident mammals are shrews (*Sorex* spp.), pikas (*Ochotona* spp.), hares (*Lepus* spp.), marmots (*Marmota* spp.), pocket gophers (*Thomomys* spp.), deer mice (*Peromyscus* spp.), voles (*Microtus* spp., *Phenacomys* spp., *Clethrionomys* spp., *Arvicola* spp.), weasels (*Mustela* spp.), bighorn sheep (*Ovis canadensis*), and mountain goats (*Oreamnos americana*) (Pattie and Verbeek 1967). Elk (*Cervus canadensis*) are reported to winter on alpine tundra in Rocky Mountain National Park (Marr 1964).

Because of its soil-disturbing activities, the most influential tundra mammal is the pocket gopher. These animals bring large quantities of soil to the surface where strong winds and runoff can move it downslope, covering some lower slope alpine communities. They may also consume considerable herbage (Stoecker and Bock 1971).

Large mammals using the alpine zone primarily as summer habitat include elk, mule deer (*Odocoileus hemionus*), coyote (*Canis latrans*), red fox (*Vulpes fulva*), black bear (*Ursus americanus*), grizzly bear (*Ursus horribilis*), bobcat (*Lynx rufus*), and badger (*Taxidea taxus*). Moose (*Alces alces*) occasionally enter the alpine zone, and on Carter Mountain in northwestern Wyoming, pronghorn antelope (*Antilocapra americana*) are present in the alpine tundra in the summer. Pattie and Verbeek (1967) report finding bone fragments of bison (*Bison bison*) on the Beartooth Plateau.

The most numerous large ungulate in the alpine zone is the domestic sheep. Domestic cattle, horses, and goats are also present in some areas during the summer months but are usually not deliberately herded in the alpine zone.

Smaller summertime resident mammals include porcupine (*Erethizon dorsatum*), marten (*Martes americana*), chipmunks (*Eutamias* spp.), and ground squirrels (*Spermophilus* spp.).

Many birds use the alpine zone, but the characteristic species is the ptarmigan (*Lagopus leucurus*) which is present yearlong. The water pipit (*Anthus spinoletta*), rock wren (*Salpinctes obsoletus*), and rosy finch (*Leucosticte* spp.) are characteristic of the alpine zone in summer (Hayward 1952). Often-seen birds of prey include the golden eagle (*Aquila chrysaetos*), red-tailed hawk (*Buteo jamaicensis*), bald eagle (*Haliaeetus leucocephalus*), and raven (*Corvus corax*).

Vertebrate terrestrial poikilotherms are rare in the alpine. The boreal toad (*Bufo boreas boreas*) is one of the exceptions. This species is resident in the alpine zone, and is presently being studied as an indicator of man-caused climatic changes in the San Juan Mountains of southern Colorado (Campbell 1971).

Alpine lakes and streams may often contain good endemic populations of trout (*Salmo* spp.), and char (principally brook trout) (*Salvelinus fontinalis*) have been introduced into many alpine lakes and streams with varying success. The only true alpine trout is the golden trout (*Salmo aqua-bonita*) which is native to the Sierra Nevada Mountains above 3000 m elevation (LaMonte 1946). This species has been introduced into some alpine lakes in Wyoming.

The major invertebrates of the alpine zone are Araneae (spiders), Formicidae (ants), and Diptera (flies, gnats, mosquitoes) (Hayward 1952). Apiodea (bees) and members of the Acrididae and Tettigoniidae (grasshoppers) as well as Lepidoptera (butterflies) are also common. Bees and flies appear to be the major insect pollinators in the alpine zone (Bliss 1962).

ALPINE ECOLOGY

Adaptations of Plants to the Environment

The major adaptations of alpine vascular plants, regardless of their taxonomy, to the alpine environment are reduction in height, perennial life cycle, and herbaceous habit. Reduction in height is genetically controlled, but phenotypic plasticity often allows considerable morphological variation. Along with reduced height, plants on exposed sites often have a dense, clumped appearance. This "cushion-plant" form is especially evident in exposed, windswept areas and has evolved in unrelated plant families. It enables the plant to take advantage of higher surface temperatures and minimizes the desiccating and abrasive effects of strong wind. In more protected areas (lee slopes, snowbanks, etc.) plants are taller, but rarely exceed 25 to 30 cm in height. Shrubs are equally reduced in height, and prostrate forms predominate (Bliss 1962).

The advantage of a perennial life cycle is permanence. Yearly maintenance can be low and reproduction must occur only at long intervals for survival. Many alpine shrubs are evergreen and do not have to deplete food reserves on a wholly new photosynthetic apparatus each year. Older leaves may also act as winter food storage leaves during the growing season (Bliss 1962).

The shrub life form is not especially common in the alpine. By far the majority of the plants are herbaceous perennials with large underground roots or stem storage systems. These perennials are of three main types: graminoid, leafy dicot, and the already mentioned cushion dicot. In a typical alpine situation, dicots generally have a deep primary root system with shoots proliferating near the soil surface (Daubenmire 1941).

Growth and Development

Breaking Dormancy.—Buds of alpine plants are formed during the previous growing season, usually late in the growing season. Dormancy may be broken as early as April or May or as late as August or September. The important factors are melting of the snow cover, an increase of soil and air temperatures to about 0°C, and the presence of liquid water. Relatively long photoperiod may also be important, but photoperiod has no effect without temperatures above 0°C (Bliss 1962).

Growth.—After dormancy is broken, above-ground shoots grow rapidly. Carbohydrates stored in roots and rhizomes are translocated to young shoots and leaves, both as new tissue and as anthocyanins, so that vigorous young shoots are often

red. Anthocyanins are effective in absorbing ultraviolet and prevent tissue damage (Caldwell 1968).

Fast-growing alpine herbaceous plants often lack pith. A hollow stem saves materials, grows rapidly, and has the advantage of internal photosynthesis with carbon recycling. Stems may elongate several centimeters a day, and the high respiration rate provides an additional supply of carbon dioxide which is used in the hollow stem where temperature may exceed that of the surrounding air by 20°C (Bliss 1966).

After leaf expansion and development of a large supply of chlorophyll, further growth is closely tied to temperature until late in the growing season when drought, photoperiod, and carbohydrate accumulation become involved (Billings and Mooney 1968).

Photosynthesis.—Alpine plants have evolved a metabolic mechanism that allows them to capture, store, and utilize energy at temperatures close to freezing in a 6- to 10-week growing season. Photosynthetic activity occurs in alpine plants throughout most of the snow-free season during daylight hours. Net photosynthesis is low in the early season due to high respiratory rates, but increases as temperatures warm and as long as moisture is available. Maximum photosynthesis is reached at flowering. Some vascular alpine plants may carry on photosynthetic activity at temperatures as low as -6°C, and lichens may photosynthesize at -24°C (Bliss 1962).

Although data are available for only a few species, it appears that alpine plants reach photosynthetic light saturation at higher light intensities than arctic plants of the same species (Mooney and Billings 1961). Photosynthetic rates for whole plants of 4.15-13.4 mg CO₂/dm² (two surfaces)/hr have been reported (Billings et al. 1966). Alpine plants may be able to photosynthesize at lower CO₂ concentrations than lowland plants.

Little information is available on chlorophyll content of alpine plants. The range of 0.18 to 0.90 g/m² reported by Bliss (1966) is comparable to that of temperate lowland communities reported by Bray (1962). Because solar radiation is higher in alpine environments, however, photo-oxidation of chlorophyll may also be high.

Respiration.—Respiration rates of 0.15 g/dm²/wk of carbohydrate have been reported (Mooney and Billings 1961), and there is evidence that dark respiration rate at all temperatures is higher in alpine plants than in lowland plants (Bliss 1962).

The principal reserve foods in herbaceous alpine plants are starches and sugars (and in shrubs, lipids). The general carbohydrate cycle is as follows: Large amounts of carbohydrates are stored in the underground parts of alpine plants at the end of the

growing season. Little of this is used during winter dormancy. After dormancy is broken, the underground reserves are rapidly depleted since respiration exceeds photosynthesis during this phenological stage. Reserve carbohydrates remain low until shoot growth is 75 to 90 percent completed. Respiration rate then drops; shoot growth slows and carbohydrate replenishment begins. Cold or cloudy weather after the rapid period of growth ceases will further deplete carbohydrate reserves, but they appear to be readily replaced after a few warmer, clear days (Bliss 1962).

Flowering.—The flowers of alpine plants are self, wind, or insect pollinated, with the first method the most common. Flowering depends on environmental conditions the year before actual flowering takes place, and both flowering and seed production decrease as environmental severity increases. Pre-formed flower buds are almost universal in both dicots and monocots in the alpine. This adaptation allows them to complete flowering even in a very short growing season. The flower bud primordia are often initiated early in the growing season, and are usually well developed by onset of dormancy. The bud can withstand very low temperatures without damage (Billings and Mooney 1968).

Reproduction.—Most alpine plants in western North America reproduce by seeds rather than vegetatively. Reproduction by seeds is more common in drier alpine sites, although layering is common in cushion plants. Vegetative reproduction by rhizomes or runners occurs more readily in mesic or wet habitats. Some alpine species also reproduce by **apomixis** (asexual seed production) and **vivipary** (germination of a propagule while attached to the parent plant). Both have survival advantages in severe habitats (Billings and Mooney 1968).

Cold growing-season temperature inhibits flowering and fruiting so that little or no viable seed is produced in many years. In other years seed crops are abundant. Because of the shortness of the growing season, seeds usually do not ripen before winter in the year they are produced. True seed dormancy is not common among alpine plants, however; the time between production and germination is environmentally imposed. That dormancy that does exist is caused by seedcoat inhibition, and can be overcome by scarification, cold temperature, light, or elapsed time (Billings and Mooney 1968).

Optimum germination temperatures are 20° to 30°C, although alternating low temperature appears to bring about higher germination success. Seeds usually germinate in early summer after snowmelt during the year following seed production. Although dormancy does not seem to be an attribute of alpine plant seeds, they will remain viable for

long periods if kept at low temperature (Billings and Mooney 1968).

Little is known of the field conditions necessary for seedling establishment in alpine species, which seems to be only a sporadic and not very common occurrence. When it does happen, it appears the first growing season is devoted primarily to establishing a root system. A relatively deep taproot enhances survival by enabling the seedling to tap soil moisture at deeper levels, and providing anchorage against heaving by needle ice (Billings and Mooney 1968).

Seedlings establish both in open areas and within the crowns of other plants, particularly cushion plants (Griggs 1956). Establishment within the influence of another plant is disadvantageous from the standpoint of light and moisture competition, but affords considerable protection in needle ice or solifluction areas. Cushion plants with several other species growing within the periphery of the crown are common. Such cushions are in many respects a microhabitat.

Dormancy.—Alpine plants beyond the seedling stage are rarely killed by the onset of winter. Winter hardening is brought on by shortening day length, lowering temperatures, and increasing drought. There also appears to be a relationship between increased sugar content (raffinose) and cold resistance (Billings and Mooney 1968).

Alpine plants released from snow cover early in the growing season take longer to go through their annual growth cycle than plants of the same species that are released later in the season. The late-released plants grow faster, but are usually smaller and produce less dry matter (Billings and Mooney 1968). Sites with a relatively long growing season show distinct aspectional differences. Species that mature at different times on the long-season sites will all be in the same developmental stage at the same time on the late-release sites.

Biomass and Productivity

Most of the biomass of alpine plants is below the ground surface. Forbs appear to have a proportionately greater amount of underground biomass than graminoids, and species on mesic sites generally have more than those on xeric sites. Thus, the effect of a moisture gradient in the alpine is greater on the underground plant parts than it is on aboveground parts.

This relationship also is true for total stand biomass in the alpine zone. From 80 to over 95 percent (dry weight) of the total biomass of a mesic site may be underground (Scott and Billings 1964, Thilenius 1975), while on a xeric site the underground biomass may be only about twice that of the aboveground biomass.

A total underground biomass of 3634 g/m² (8.92 g/m² = 1 lb/ac) has been measured on a mesic sedge meadow site on Mt. Washington, New Hampshire (Bliss 1963). Thilenius (1975) recorded a total underground biomass of 7186 ± 490 g/m² on an alpine turf site at 3475 m elevation in the Medicine Bow Mountains. The soil depth at this site was 19.5 cm. Total aboveground biomass at the same time was 223 g/m², for an aboveground-belowground percentage ratio of 3:97.

The aboveground-belowground percentage biomass ratio varies with site characteristics. For example, a mesic site in the Medicine Bow Mountains of Wyoming had a total standing crop of 1400 g/m² with 1100 g/m² underground (21:79). The corresponding values for a xeric site in the same area were 750 g/m² belowground and 350 g/m² aboveground (47:53) (Scott and Billings 1964).

The majority of the aboveground standing crop is produced by relatively few species. This seems to be a general rule in alpine communities, where although 40 or more species may be present, usually 4 to 6 of them will produce more than 75 percent of the total biomass (Scott and Billings 1964, Thilenius et al. 1974).

The productivity of alpine sites varies considerably from year to year. Total aboveground standing crop of a *Geum rossii* turf community ranged from 100-150 g/m² over a 4-year period in the Medicine Bow Mountains (Thilenius et al. 1974). However, the contribution of forbs and graminoids remained within one or two percent of an 80:20 ratio regardless of the total standing group. Scott and Billings (1964) report a range of 14 to 348 g/m² of aboveground standing crop on 50 sites ranging from xeric to very mesic in the same general region. Most of the values were between 100 and 200 g/m².

Productivity (rate of increase in standing crop/unit time) of alpine communities on an annual basis is relatively low. Bliss (1962) gives a range of 40-128 g/m²/yr for aboveground biomass, quite low in comparison to other terrestrial communities (Rodin and Bazilevich 1964). However, the alpine growing season is only 30 to 75 days long. When productivity is calculated on a per-day basis, alpine sites may exceed comparable rates from lowland herbaceous communities. Aboveground standing crop may increase at rates of 0.5 to 5.0 g/m²/day during the growing season (Bliss 1966), and if root productivity is included may be as high as 11 g/m²/day on moist sites (Scott and Billings 1964).

Phytosociology

The current concept of alpine communities regards the vegetation as a complex mosaic of community type arranged along environmental gradients. Topographic site, degree and duration of

winter snow cover, and wind exposure are the major influences (fig. 9).

The combined influence of these major features of the alpine environment is basically a gradient of available moisture, and consequently temperature, and with the exception of the presence of a geological substratum of rocks with special chemical characteristics such as limestone or serpentine, the moisture gradient controls the structure, composition, and pattern of alpine communities.

It must be remembered that the gradients shown may be represented in the microlandscape as well as the more easily recognized macrolandscape. Thus phytosociological units may be present on a minute scale. As Marr (1961) so aptly put it, "... one's foot may rest at one instant on two dissimilar stands." This does not mean there are no large areas of phytosociologically similar vegetation units in the alpine zone, for there are, but their environmental gradients will show a minimal change across the area.

Except for certain species (such as *Oxyria digyna*) little is known of the exact autecological requirements of individual alpine species. The requirements of a given species are usually inferred from the general type of habitat where it predominantly occurs. This is complicated by the fact that many alpine species seem to have a wide autecological amplitude, and can occupy what appear to be different habitats. Usually there will be differences in size, abundance, or productivity which will allow the most preferred habitat to be distinguished. Thus, *Deschampsia caespitosa* may occur as a very small, individual plant in what appears to be a xeric habitat, but grows profusely in mesic habitats and is often a dominant species in such locations. However, because of the already mentioned features of microlandscape, it is necessary to be very careful in assessing if the site where the plant is growing is actually xeric.

Because of variations in microhabitat and the wide ecological amplitude of alpine species, designation of communities on the basis of species composition alone is difficult. Communities so determined are liable to have a great variation in composition from place to place. This has led to the current use of ordination (mathematically derived arrangement of species or sample stands along environmental gradients) as a synthesis technique in alpine phytosociology (Johnson and Billings 1962, Smith 1969a). Gradients may be single factor (light, moisture, etc.) or multifactor, such as those derived from principal component analysis.

The use of gradient analysis does not preclude a classification of alpine communities, and indeed, even the most ardent users of ordination will refer to community types, since it is difficult to describe a vegetation only by mathematical coordinates.

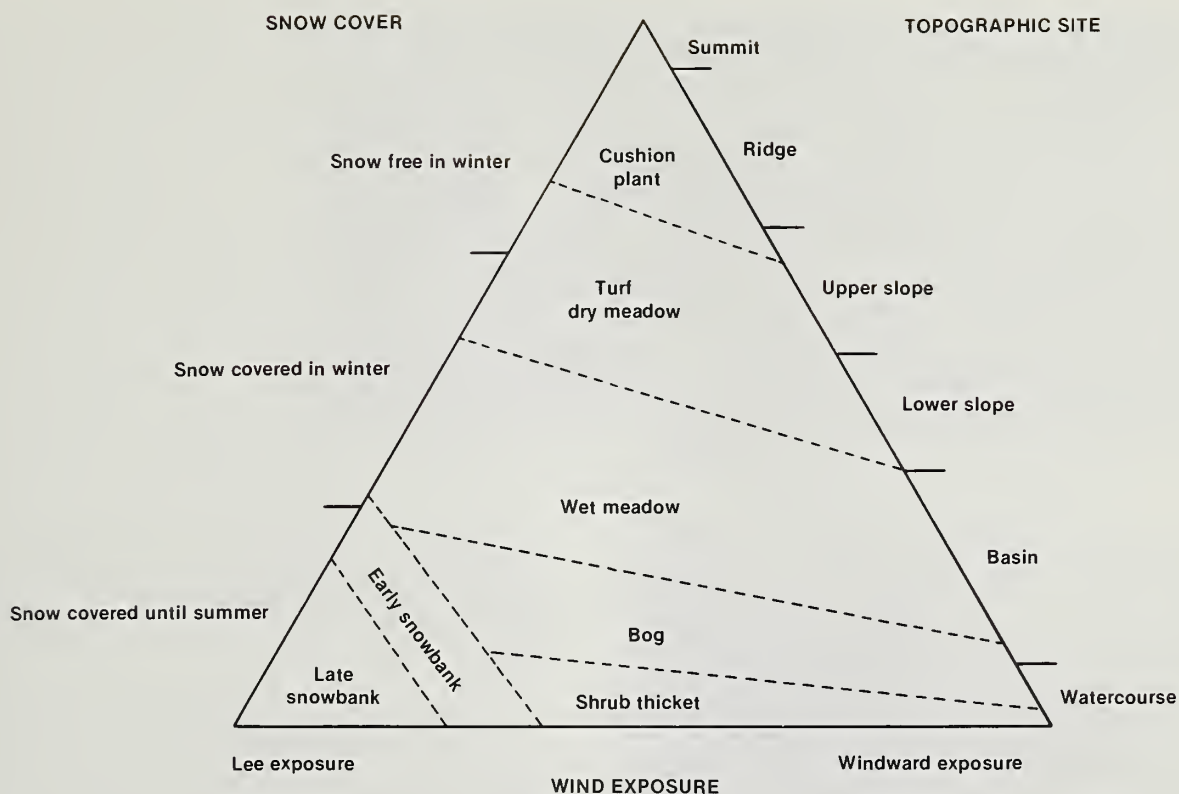


Figure 9.—Alpine vegetation as related to topography, wind, and snow cover (adapted from Johnson and Billings 1962).

While the species composition of alpine communities may be highly variable, the physiognomy of alpine communities shows a rather remarkable similarity in response to environment. Thus, the general trend from a cushion plant community on exposed rocky ridges (fig. 10), to turfs (fig. 11), to

the wet meadows, bogs and shrub thickets (fig. 12) in areas of high moisture are commonly repeated in most alpine locations.

Competition between species appears to be less intense in alpine plants than in those of lower elevation. This may be caused at least partially by the



Figure 10.—Cushion plant community on exposed rocky ridge, Absaroka Mountains, Wyoming.



Figure 11.—Rocky alpine turf community on side slopes, Absaroka Mountains, Wyoming.



Figure 12.—Shrub thicket community, Wind River Mountains, Wyoming.

generally scattered distribution of alpine plants. In this situation, individual plants have only a very local effect on their environment in comparison to plants at lower elevation. Thus the major responses of alpine plants are to environment rather than biological influences. Lack of competitive ability may be one reason why alpine plants do not invade downward into the milder environments of lower regions.

Nevertheless, alpine species are not completely noncompetitive. Griggs (1956) has described the invasion and eventual replacement of cushions of *Silene acaulis* by other species in the alpine zone of Colorado. The changes are on a very small scale, however.

The classic concepts of climax and succession as developed in temperate, low-elevation regions do not appear to be applicable in the alpine zone (Churchill and Hanson 1958). Intense cryopedogenic action creates a dynamic instability in both vegetation and soils. Nevertheless, in areas where relatively constant environmental gradients exist for a long time, a steady-state community pattern can evolve which may be analogous to the climax community of lower elevations. Changes occur constantly within these steady-state communities, however.

Fire, an important successional influence of lower elevation zones, does not appear to be influential in the alpine zone. In general, alpine communities are usually too wet to burn, or the plants are too widely spaced to carry a fire. Billings (1969) has described the effects of fire on timberline forest (ribbon forests and Krummholz), but these are not true alpine sites. He does indicate, however, that herbaceous vegetation adjacent to or between the rather frequently burned timberline forests is very similar in species composition to the alpine tundra immediately above, and that alpine tundra may replace burned timberline forests as a result of changing snowdrift patterns.

RANGE MANAGEMENT IN THE ALPINE ZONE

In considering grazing use, two points must be kept in mind. First, the alpine zone is, for the most part, usable for grazing only during the normal 6- to 8-week summer period, and the length of this use

season cannot be predicted. Furthermore, freezing temperatures, snow, and high winds can and do occur at any time during the use season. Wild ungulates using the alpine zone will move into lower zones during such critical times, but domestic livestock present a more difficult situation, and severe losses may occur.

The second point pertains to the control of domestic livestock grazing in the alpine. In the western United States, most of the alpine zone is Federal land, and the grazing is controlled by agencies of either the U.S. Department of Agriculture (Forest Service) or the Department of the Interior (Bureau of Land Management, Bureau of Indian Affairs, or National Park Service). Thus, the kind and extent of grazing reflect the policies and experience of the Federal agencies; where mismanagement has occurred or is occurring, at least part of the blame lies with them.

Concern for the condition of alpine ranges is reflected in reduction in grazing use by sheep. From 1939 to 1959, sheep numbers on alpine ranges were reduced approximately 50 percent (Wasser and Retzer 1966).

Domestic Livestock Grazing

Sheep are the principal domestic livestock using the alpine (fig. 13) zone, since normally available breeds of domestic cattle are poorly adapted to the cold, windy environment. Cattle also suffer from **brisket disease**, a congestive failure of the right side of the heart brought about by the stresses of high elevation (Alexander and Jensen 1959). Thus, range

management in the alpine refers almost entirely to management for sheep.

Sheep were among the first domestic animals introduced into the New World, but up to the time of the Civil War were relatively unimportant on western ranges. During the period 1865 to 1901 sheep numbers rose spectacularly. This was the period of trail herding, when as many as 600,000 sheep were trailed from California and Oregon to stock ranges farther east and to fattening and marketing points in the Midwest (Wentworth 1948).

The early sheepmen grazed their animals year-long, and moved up the mountains into the alpine zone—more or less following the receding snow line—for summer grazing. Sheep numbers peaked in the western United States about 1910, and have declined since (Stoddart and Smith 1955).

Many alpine ranges have been used for summer grazing continuously since the mid to late 1800's. For example, the Beartooth Plateau in northwestern Wyoming and southeastern Montana has been grazed by sheep since 1893 (Pattie and Verbeek 1967). Because of this long-term use, it is often difficult to determine what the "natural" state of many alpine ranges was.

Grazing Systems

Specialized grazing systems (deferred, rotation grazing) are being used on alpine ranges in the Intermountain Region (R-4), and are being initiated in the Northern Region (R-1) of the Forest Service. In the past, a crude form of deferred grazing was accomplished by sending sheep up the opposite end



Figure 13.—Sheep grazing alpine rangelands, Carter Mountain alpine Research Site, Absaroka Mountains, Wyoming.

of sheep driveways in alternate years. This deferred the grazing on opposite ends of the range to some extent, but the center was grazed similarly in all years.

Historically and currently, most sheep in the alpine are grazed under the care of a herder. Prior to governmental control of the ranges and the introduction of grazing allotments, sheep were grazed in tightly grouped bands and continuously bedded in the same location, usually near water, for several nights in a row. These practices resulted in large losses of forage through trampling and in soil damage from excessive trailing to and from the bed-ground and to water.

Herding practice on National Forest lands (USDA-FS 1968a) requires the sheep to be distributed in loosely bunched (open-herded) bands and to be moved slowly, but steadily, in one direction while grazing (progressive herding). The bands should be herded by guiding the movement of the lead animals rather than herding from the rear. Excessive use of dogs is not recommended. Herding must be planned so the band reaches water only once a day, and the bands must be grazed quietly to water, not driven. A given area should be grazed over only one time during the grazing season, and the sheep should not be allowed to remain in a given area long enough to cause excessive forage utilization. One-night bedding is recommended, with the band being bedded down on a well-drained site near where they finish grazing. Salting is usually done in the bedding ground, and movable containers should be used.

Ranges grazed under these conditions seldom show excessive use of forage, and their condition may improve considerably. For example, Strickler (1961) found that 18 years of a well-conceived and directed herded system of grazing improved high-elevation ranges in the Wallowa Mountains of northeastern Oregon. Herbage production increased about 2.7 times (from 88 g/m² to 241 g/m²). There was also a marked decrease in soil erosion attributed to overgrazing. Gullied meadows were healing, and the general condition of the range was considered to have increased from poor to good.

Whether or not good grazing systems are applied depends to a great extent upon the desire and experience of the herder and on the control exerted upon him. Because good herders are hard to find, a third system, called "herderless" grazing, is sometimes practiced. Under this system the sheep are turned loose on the range and allowed to distribute themselves and graze according to their own wants. Herderless grazing is not new. Jardine (1912) reported on a 5-year study on mountain range (alpine?), and the practice is normal in the mountain areas of New Zealand and Scotland.

Claimed advantages of herderless grazing include a wider distribution over the range, with the

sheep scattering in bunches of 5 to 25 animals. Concentrations on bedgrounds are also minimized, and trailing damage is greatly decreased. Better weight gains on lambs also have been reported (Jones and Paddock 1966).

However, Strasia et al. (1970), in their study of herded versus unherded sheep, indicated the unherded band generally moved as a single unit although often spreading over an area of up to 2.5 km². These sheep tended to use the same areas for bedgrounds for long periods, and banded together into one group when bedding. The distributional behavior of the sheep may have been conditioned by herding during the rest of the year. The breed may also have influence. Rambouillets, which have a strongly gregarious habit, were used in the area studied by Strasia et al. (1970), while Jones and Paddock (1966) reported on the behavior of Columbia sheep, which may not have as strong a herding instinct.

A major disadvantage of herderless grazing is the need for fencing to limit movement. On alpine ranges, fences may be difficult to build and maintain. The tendency of unherded sheep to return to the same bedground can also be disadvantageous, as they appear to prefer steep rocky areas, which may be easily erodible (Retzer 1962).

Water is usually not a problem on alpine ranges, but if watering sites must be developed, they can be expensive. Salt must still be supplied to the sheep, but one man can do this for several bands. Collection of the sheep at the end of the grazing period could be a problem if they scatter widely. Nevertheless, large numbers of unherded sheep are "mustered" (collected) in the fall in the New Zealand Mountains where, except for lower elevations, conditions are very similar to those on alpine ranges in the western United States.

Research in progress on herderless grazing on an alpine range in northwestern Wyoming² indicates for the period 1965-70, total foliage cover increased 28 percent on unherded range as compared to 6 percent on an adjacent range where the sheep were herded in the normal manner. Major increases on the unherded allotment occurred in sedges (9 percent) and cushion plants (14 percent). There was no difference in the weights of lambs from the two ranges. Average weight gain was about 9 kg/lamb over a 60-day grazing period, with a maximum gain of 16 kg/lamb.

Predation may increase with herderless sheep grazing. The extent of predation on sheep is, of course, a subject of controversy and conjecture.

Because alpine ranges are often remote and on rugged terrain, few roads are present and getting

²Unpublished data on file at the Rocky Mountain Forest and Range Experiment Station's Research Work Unit, Project 1703, Laramie, Wyoming.

sheep to the range is difficult. Sheep driveways have been a common feature of many National Forests in the western United States. These driveways are usually noteworthy for the extent of range deterioration present on them. Forage may be practically nonexistent, and the plants that do grow are often worthless as forage or even poisonous. Erosion has been greatly accelerated by the trampling of many animals over many years, and the loss of the plant cover may cause greatly accelerated runoff and stream siltation. Because such range deterioration is no longer tolerated, many driveways have been, or will be, closed. Rehabilitation of the driveways will be expensive, and in the alpine zone, at least, the techniques of rehabilitation, both cultural and biological, are not well known.

Range Readiness

Conditions of soil moisture and plant development determine when a range is ready to be grazed. In the alpine zone, the duration of snow cover is considered to be the primary factor influencing the phenological development of plants (Holway and Ward 1965). Growth starts as early as mid-May on snow-free sites, but on areas where snow accumulates it may not start until early August. Regardless of the time growth starts, most alpine species show definite signs of dormancy by mid-September.

On lower elevation ranges, the proper time to start grazing may often be judged by the phenological state of certain species (Stoddart and Smith 1955). On alpine ranges, while the time period for a given phenological stage appears to be rather stable for an individual species, the time of initiation of a particular phase will vary considerably from site to site, and from year to year at a given site (Holway and Ward 1965). Thus, it appears phenology may not be a good indicator of readiness for alpine ranges.

Traditionally, sheep are turned onto most alpine allotments between July 10 and 15, where they graze for a 60-day period. Based on the growth and development of the plants, this appears to be a suitable time to start grazing. An earlier date would allow grazing during the period of most active growth, which might increase the chance of trampling damage because of wet soils. A later date would extend the grazing season to the end of September when the chances of heavy snowstorms are much greater. Early fall snowstorms are disadvantageous in two ways: (1) the obvious danger of high losses of sheep, and (2) the danger of heavy trampling damage to the soil from large numbers of sheep moving across areas where the soil has been moistened by the snow, but where it is not yet solidly frozen. A further disadvantage of late-season grazing is the removal of preformed flower buds

(see Growth and Development) and the consequent alteration of the flowering-root reserve replenishment cycle which might influence plant growth during the coming growing season.

Quantity and Quality

Quantity.—The small-scale distribution pattern of alpine plant communities and their rather nebulous nature makes it difficult to assess forage production over large areas of range. Production can vary greatly between points separated by only a few meters. The most productive sites are those with high available moisture. The least productive are freely drained, rocky ridges or other terrain exposed to cold, desiccating wind. Within this range of sites, total herbage production can vary from almost nothing to over 300 g/m². On intermediate sites (alpine turf), production will usually be in the range 100-200 g/m² (Scott and Billings 1964, Thilenius et al. 1974). However, these figures can vary as much as 50 percent from year to year, depending on the immediate growing season conditions. Production usually peaks 3 to 4 weeks after snowmelt (mid-July) and then slowly declines (Billings and Bliss 1959).

From the standpoint of grazing management, both of the site extremes mentioned above should be considered as unsuitable range: the wetter sites because of their importance as aquifers and the susceptibility of the vegetation to trampling damage, and the drier sites because of their low herbage production and the high erosion potential of the exposed regolith.

Areas with steep slopes (+40°) should also be considered unsuitable range, regardless of the degree of plant coverage, since it is doubtful if they can be grazed without damage. Lesser slopes are suitable (Schwan and Costello 1951). Large thickets of upright shrubs may contain some forage, but are often so dense sheep cannot enter without causing severe trailing or without heavy overbrowsing of the edges. Unless they are relatively open, such thickets should be considered as unsuitable range. Sheep should also be kept from snowbanks and the wet ground surrounding them. Slopes holding late-lying snowfields are also difficult to graze properly, and should be considered unsuitable range even though they may not be especially steep.

The plant production of a site will vary not only with yearly growing conditions but also with the specific composition of the site. Paulsen (1960) found turf stands dominated by *Kobresia* spp. and *Carex* spp. to average about 40 g/m² of total herbage (air-dry weight), while those dominated by *Deschampsia caespitosa* averaged about 66 g/m². Turf sites dominated by *Geum rossii* in the Absaroka Mountains of Wyoming are more productive. Average herbage production there varies from 92 to 118 g/m² depending upon the subordinate species

present. Similar alpine turf communities in the Medicine Bow Mountains are even more productive, producing 100 to 150 g/m² of air-dry herbage (Thilenius et al. 1974). Thus a total herbage production of 90 to 100 g/m² is a reasonable value for grazable alpine turf sites.

Quality.—Although little research has been done on the nutritive quality of alpine plants, the available information indicates they provide generally high-quality forage. The most complete work was done by Johnston et al. (1968) on 21 species of plants from alpine tundra at 2200 m elevation in the southeastern Canadian Cordillera. Crude protein, calcium, phosphorus, ash, silica, and cellulose and in-vitro digestibility were determined for graminoids at the leaf, heading or flowering, ripe seed, cured, and weathered stages of growth, and for forbs and shrubs at the first three growth stages listed above. Percentages of crude protein and phosphorus of all species decreased with advancing maturity while calcium and cellulose content increased. In-vitro digestibility also decreased as the plants matured. Alpine grasses, on the average, contained about 50 percent more crude protein and 100 percent more phosphorus than grasses from lower elevations, while alpine sedges had about twice the protein and phosphorus of similar nonalpine species. Calcium:phosphorus ratios were low, and digestibility high for all species at all growth stages, and the vegetation was considered to provide a nutritious forage during the summer.

Other studies have shown that crude protein content of alpine species during the summer was adequate for lactating ewes (Smith and Johnson 1965). Golley (1961) reported average energy values of alpine plants to be higher than those from plants of lower elevations, and Bliss (1962) associated the high energy content of alpine plants with their high lipid content. However, Smith (1967) reported gross energy values of aboveground parts of alpine plants from Wyoming to be below the average values given by the other two authors. Differences in the ecosystems where the plants grew (New Hampshire and Wyoming) may account for some of the discrepancy.

Smith (1969b) tested the in-vitro digestibility of 54 species of alpine plants from the Absaroka Mountains of Wyoming. At the time of maximum standing crop there was a spectrum of digestibility ranging from 78 to 35 percent. As a group, grasses averaged 64 percent, sedges and forbs 60 percent, and cushion plants 44 percent digestibility. Strasia et al. (1970) also indicate alpine range provides a high quality diet.

Native *Trifolium* species are common on alpine ranges in the Rocky Mountains. Hamilton (1961) examined the chemical composition of three species (*Trifolium parryi*, *T. nanum*, *T. dasyphyllum*) common to the Wyoming alpine, and reported all to be

satisfactory sheep forage. Crude protein at bloom exceeded that necessary for the nutritive requirements of sheep, and calcium and phosphorus were also adequate, while carotene content was considered to be excellent.

Except for some of the work of Johnston et al. (1968) nothing is known of the quality of the forage during the dormant season. While this is unimportant for domestic livestock, it may be very important for wild animals (such as bighorn sheep or mountain goats) that may winter on alpine ranges.

Preference and Utilization

Preference.—Preference of a sheep for a given forage is determined by its sense of smell, taste, and touch rather than sight (Arnold 1966a, 1966b), and will vary with the plant community, associated species, growth form and growth stage of the plants, weather conditions, intensity of grazing (both past and current), and the general activity and whims of the animal (Stoddart and Smith 1955).

The techniques by which preference is established also influence ratings. Three techniques are available: (1) examination of the vegetation directly; (2) use of fistulated animals; and (3) particularly with wild species, the use of sacrificed animals. All have disadvantages. In the first, it may be difficult to detect use because of the growth stage of the plant, its life form, and because removal of plant parts by grasshoppers, rodents, etc. or by mechanical abrasion due to wind, cannot be differentiated.

The difficulty with fistulated animals is that the effect of the fistula on the animal's habits is unknown. Samples from shot or trapped animals only reflect the forage an individual animal has consumed immediately before collection. Furthermore, the animal is removed from the population, which may alter the habits of the remaining animals, and the method of collection may disturb their normal feeding habits. Of the three, the use of fistulated animals appears to be the most certain method. To be most effective, however, a measure of the abundance or scarcity of plant species must also be obtained (Stoddart and Smith 1955).

With many variables influencing diet selection, a great deal of variation in reported species preference ratings is not surprising. Most of the reported information on sheep diet preferences does not come from true alpine range, but rather from subalpine ranges. The general consensus of these studies is that sheep generally prefer forbs. Estimates of the percentage of forbs in the diet range from a high of 89 percent (Stevens 1966) to a low of 24 percent (Pickford and Reid 1942). The low of 24 percent was established on a grass-dominated range; a value of 60 to 70 percent forbs appears to be about average.

Less information is available from true alpine range. Johnson (1962) gave a list of preferred species, but did not quantify which were the most used. He listed seven graminoids and eight forbs as being "consistently grazed" and six graminoids and two forbs as "usually grazed."

The most complete study of sheep forage preference on an alpine range is that of Strasia et al. (1970) using esophageal fistulated sheep. They concluded:

1. The diet was composed of a large number of species, none of which were dominant. The most important forb species (with percentages in parentheses) were *Trifolium dasyphyllum* (14), *Polygonum bistortoides* (11); *Geum rossii* (10); *Trifolium nanum* (10). Fescues (*Festuca rubra*; *F. ovina*) were the preferred grasses (13).

2. Overall, forbs made up 58 percent of the diet, but unherded sheep grazed less forbs (52) than herded sheep (65).

3. The sheep were more selective in their choice of individual graminoid species than of individual forb species, and the proportion of forbs in the diet was related to their relative availability.

4. The amount of graminoids consumed increased in the latter part of the grazing season when forbs became less available due to utilization or disintegration, or less desirable due to maturity.

Even less is known about the diet preferences of wild herbivores using alpine range. The available information for bighorn sheep is biased toward the fall or winter season, since the samples have usually been obtained from hunter-collected or winter-killed animals. At this time the bighorns are usually not using alpine range. This is reflected in the amount of browse from nonalpine shrub species reported in the literature (Honess and Frost 1942, Smith 1954, Moser 1962). The published information indicates that graminoids comprise 70 percent and forbs about 5 to 7 percent or more of the bighorn diet (Moser 1962). However, considering the post-growing season bias of the data and tendency of domestic sheep to use more grass in late season (Strasia et al. 1970), it would not be surprising to find forbs a much more important dietary item in the spring and summer. Work is needed on this aspect of bighorn sheep food habits.

Forbs are the preferred dietary items of pocket gophers, and removal or reduction of the forb component with herbicides may cause a large decline in pocket gopher density (Tietjen et al. 1967). Osborn (1958) found that pocket gophers grazed alpine tundra on Niwot Ridge in Colorado heavily enough to give it a "mowed" appearance, and Willard (1960) described the "shredding" of cushion plants by pocket gophers. Paddock (1966) indicates forbs are more important than graminoids in the "hay"

harvested by pika. Regardless of their special dietary preferences, it is obvious that small mammalian herbivores are an important grazing influence on alpine ranges, and must be taken into consideration in proper range management.

Similarly, the diet and effects of invertebrate herbivores need to be determined. Although some work is available on certain alpine invertebrate herbivores, such as Gregg (1947) and Taussig (1962) on ants, and Alexander (1951) on grasshoppers, much is unknown. Invertebrate microherbivores may be as important an influence on alpine vegetation as the more easily seen large herbivores.

Utilization.—Previously, 90 to 100 g/m² of total herbage has been suggested as a reasonable value for grazable alpine range. This is total herbage; usable forage is another thing. Proper use factors are available for only one alpine species, *Deschampsia caespitosa* (USDA-FS 1968b). As far as is known, no research has been done on the effects of herbage removal on alpine plants. This lack of information may tend to make managers conservative in the amount of use they will allow on alpine ranges. Nevertheless, studies of the effects of different amounts of herbage removal at different plant growth stages are needed for the major alpine species to establish a sound basis for determining levels of allowable utilization.

Light to moderate removal (20 to 30 percent of the herbage of the major species) appears to be a reasonable range of allowable use. This means from 200 to 300 kg/ha of forage would be available on an average grazable alpine turf site.

More important than knowing how much herbage can be removed, however, is knowing **how much should be left** for ecosystem maintenance. Approaching utilization from this standpoint provides for the physiological needs of the plant species.

Although little work has been done on the amount of forage removed by domestic sheep grazing alpine tundra, what is available suggests that, under a properly applied grazing system, actual forage utilization is light. Paulsen (1960), in his study of alpine range in the central Rocky Mountains determined an average utilization of only 7 percent. On the Carter Mountain alpine range in northwestern Wyoming for the period 1965-70,³ the average percentages of use recorded on six classes of forage were as follows: grasses 8.0, sedges 11.1, *Geum rossii* 4.6, *Trifolium* spp. 20.3, forbs 5.0, and cushion plants 1.0. The average of all classes is about 8.3 percent, which agrees quite well with the 7 percent determined by Paulsen. Only the *Trifolium* spp. appear to receive more than very light use.

³Unpublished data on file at the Rocky Mountain Forest and Range Experiment Station's Research Work Unit, Project 1703, Laramie, Wyoming.

The study by Strasia et al. (1970) showed *Trifolium* spp. to be one of the major dietary items of sheep grazing this same range.

Not all of the use recorded may be by domestic sheep, as bighorn sheep, pronghorns, elk, and mule deer also graze this range. While microtines are rare, invertebrate microherbivores are common, and certainly contribute to forage utilization, but to an unknown degree.

The daily forage intake of sheep using alpine range in the western United States has not been determined. Values ranging from 0.7 to 5.2 kg/day/sheep are given by Rawes and Welch (1969) for tundra sites in Scotland. The Range Environmental Analysis Handbook (USDA-FS 1968b) uses a value of about 80 kg for a sheep animal-unit month (AUM) (about 2.7 kg/day). This is higher than the average value of 1.7 kg/day calculated from Rawes and Welch (1969). However, the Forest Service "sheep" is actually a unit of ewe and lamb.

At the rate of 2.7 kg/day/sheep unit, 162 kg of forage are required for each sheep during the 60-day grazing season now used on most alpine sheep allotments under Forest Service jurisdiction. Recommended band size is from 1,000 to 1,200 sheep units (USDA-FS 1968a). Therefore, the gross intake of forage should be about 194,400 kg for a 1,200-animal herd for the grazing season. If, as determined previously, average herbage production is 1,000 kg/ha and proper use is 30 percent, then 300 kg/ha of forage are normally available and approximately 666 ha of usable alpine range are needed to support the normal size sheep band for a 60-day season. This converts to a stocking rate of 1.85 sheep units/ha/60-day grazing season or 0.54 ha/sheep unit/month (SUM). Recommended stocking rates (USDA-FS 1968b) are from 0.1 ha/SUM on range in excellent condition to 2.2 ha/SUM on range in low-poor condition. Range stocked at the rate of 0.54 ha/sheep unit/month would be considered good to low-good condition.

Range Condition and Trend

Condition.—While the condition (health) of alpine ranges is of utmost importance in judging the effects of range management, this factor appears to be poorly understood. As with other types of range, condition standards are based on the vegetative component, generally the amount of "desirable" and "intermediate" species encountered in a sample stand, and a rating of "soil stability condition class," based on the amount, extent, and type of soil erosion present.

The Range Environmental Analysis Handbook (USDA-FS 1968b) for the Rocky Mountain Region (R-2) states, "the description [of condition] is always relative to a standard or ideal for that particular range type." The problem on alpine range is

how "ideal" is defined. Schwan and Costello (1951) provided a list of criteria and standards for range condition classes in the Rocky Mountain Region, and these classes appear to be the basis for the range condition scorecard standards for alpine range R-2 in the Range Environmental Analysis Handbook. When the condition classes are carefully read, they appear to better describe a continuum of site and vegetation which occurs from a mesic meadow to a xeric cushion plant community than they do a retrogression of a given type of site from a so-called "ideal" state to one with a great deal of disturbance.

The description of vegetation composition for alpine range in excellent condition most closely characterizes an alpine meadow dominated by *Deschampsia caespitosa*, although mention is also made of *Kobresia* spp. being present as a sod or turf, and *Salix* spp. being present on the better sites. According to Marr (1964), the *Kobresia* stand-type is found in areas free of snow for most of the winter, while the *Deschampsia* stand-type occurs in areas snow covered through the winter; *Salix* dominated communities are confined to semi-hydric locations. Thus, three quite different alpine plant communities growing in different environments are combined in the standards for excellent-condition range.

The remaining condition classes are supposed to define the extent of retrogression from the "ideal." Yet, the "good" condition description most aptly applies to the ecotone between mesic alpine meadow and alpine turf; "fair" condition the true alpine turf community usually dominated by *Geum rossii*; "poor" condition the transition between turf and cushion plant communities; and "severely depleted" the cushion plant community of exposed, xeric sites or a community present under very late-persisting snowbanks. Thus, there definitely appears to be confusion between the health status of the range and the kinds of range present on different sites. If the standards for an alpine meadow community are applied to a cushion plant community, the latter must inevitably be classed in poor or severely depleted condition. Regardless of management, it is very unlikely a cushion plant community will develop into an alpine meadow community. An area of range classified as poor under the present standards may be, for its site, in excellent condition.

The classification of different alpine plant species as "desirable," "intermediate," and "least desirable," brings up the question, desirable for what purpose? The implied answer is, desirable both for protection from soil erosion and as forage. The Range Environmental Analysis Handbook indicates graminoids are best adapted to holding the soil because of their rooting habits and because they produce effective litter. However, alpine forb species also have very extensive root systems

(Daubenmire 1941) and may have excellent soil-holding ability, while cushion plants provide excellent protection for the soil surface beneath them. Furthermore, that "grasses produce more effective litter [than forbs]," must still be determined in the alpine zone (and in other range types, for that matter). It should be remembered that alpine communities on less than mesic sites are often forb dominated. Examples are *Geum rossii* turf (Scott and Billings 1964), *Artemisia scopulorum* garden (Willard 1963), and *Dryas octopetala* terraces (Bamberg and Major 1968).

From the standpoint of forage, the present classification of desirability is also of doubtful value in the light of more recent knowledge. For example, both *Geum rossii* and *Polygonum bistortoides* are classed as "least desirable" species. Yet Strasia et al. (1970) show these to be major items in the diet of domestic sheep using alpine range, and "desirable" species such as *Deschampsia caespitosa* only a minor diet item. This does not necessarily mean *Deschampsia caespitosa* is poor forage, but rather it is a low-preference forage in the area studied; in another area it may be highly preferred. Preferences need to be determined before classifying any species in a given value category.

To properly assess the validity of the present soil stability condition classes, the very dynamic nature of the alpine ground surface must be carefully considered. This factor, discussed earlier, need not be repeated here except to say the normal processes of cryopedogenesis and natural erosion can cause many of the features listed as representative or retrogressing soil stability in the Range Environmental Analysis Handbook. That the activities of mismanaged livestock can also cause or increase such erosion features is not questioned; but that such features are due only to mismanagement must be carefully determined, especially in the alpine zone where they are common landscape features even on range never grazed by domestic animals. Areas with high erosion, or erosion potential, should be considered as unsuitable range regardless of the cause of the erosion.

Trend.—Range trend is defined as a change in condition over time, and is usually determined by making measurements at intervals of several years (often 5 years) with little or no assessment during intervening years. Regardless of the suspect nature of the condition assessment criteria expressed above, it appears that such time-separated measurements can neither validly express changes, nor attribute any changes that might be measured to range management. This is particularly true on alpine ranges, where seasonal growth varies greatly and active erosion is normal and commonplace. To validly assess trend, measurements must be made at yearly intervals and take into account the current

growing conditions along with site differences and management.

It may also be possible to make measurements at very long intervals (such as Strickler 1961) so that short-term variations are masked, but waiting 20 years to determine if correct management is being used is probably not feasible.

Forest Service policy, as set forth in the R-2 Range Environmental Analysis Handbook, is to reread transects at intervals which fit local conditions; no set time interval is prescribed.

Recommendations.—Prerequisite to understanding alpine range condition and trend is a thorough understanding of alpine ecology, and how it varies from the ecology of lower elevation rangeland. Knowledge of alpine geomorphology is included in alpine ecology, especially with regard to the processes of congeliturbation and other cryopedogenic processes. A sound ecological classification of alpine range is also needed. This classification should determine the environment-site-vegetation units present in the alpine zone, and measure the within- and between-year variations of the units to define the limits of normal variability.

Information of this type would be acquired both on areas grazed by domestic livestock, and areas protected from or never grazed by livestock, if the effect of grazing is to be determined. Measures of the climatic environment must be included along with site features (topography, geological substratum, kind and duration of snow accumulation). Measures of the vegetation alone will not provide a suitable basis for classification because of the nebulous nature of alpine plant communities.

Some work on the classification of alpine communities in relation to site and environment in the Rocky Mountain Region is available, particularly in the Colorado Front Range (Osborn 1958, Willard 1960, Marr 1961); much of the recognized work has been done in Wyoming (Johnson 1962, Johnson and Billings 1962, Smith 1969a). Work is currently in progress on a classification of alpine range in the Absaroka Mountains (Thilenius and Smith [in press]).

Condition and trend standards for alpine range in the Intermountain Region (R-4) are based on the work of Lewis (1970), and many of the above comments do not apply. Lewis very clearly recognized the differences between range site potential and range health, and appreciated the unique features of the alpine soils. The Southwestern Region (R-3) uses the R-2 standards, but has modified them in light of Lewis' work. Alpine range is not recognized in the Pacific Southwest (R-5), and the Pacific Northwest (R-6) (personal communication, Regional Range Staff Officers).

Geographic limits and variations in units must also be defined. It is useless to try to apply standards

determined for the *Kobresia* turf community of the Colorado Front Range to the conditions in the Absaroka Range of Wyoming, since the *Kobresia* turf community does not occur there. Thus, it may be necessary to define standards for individual National Forests, rather than Regionwide.

Finally, the Parker loop transect (Parker 1954) used to measure the vegetation component apparently does not do the job it was supposed to do (Hutchings and Holmgren 1959, Francis et al. 1972) and needs revision.

Measurement of range condition and trend is the epitome of applied ecology and is the basis on which the management program is judged. Knowledge of management effects on alpine range is of utmost importance, and good standards are essential.

Range Improvement

Range improvement refers to: (1) the use of manipulative processes such as herbicides, fertilization, and seeding, and (2) structural additions such as fences, water developments, and trails or roads. Little information is available on the latter since they have not been needed on alpine range to any great extent under the current system of herded sheep management. With the introduction of unherded grazing for sheep, both fences and water developments may become necessary.

On the Carter Mountain Alpine Range Research Area in northwestern Wyoming, a standard Forest Service four-strand barbed wire fence is used to limit the movement of the unherded band. This fence has withstood alpine conditions since 1965, with only the usual maintenance by the permittee. Duran and Kaiser (1972) estimate a cost of \$2,500/km for fences on alpine range.

Three water developments have been installed at Carter Mountain to improve distribution of the unherded sheep. These consist of a fenced spring area with a steel culvert for a spring box, plastic pipe for waterlines, and commercially available metal troughs. The only unusual part of this installation was that all materials were air-lifted to the sites by helicopter. While expensive, the use of helicopters to ferry construction materials saved a great deal of time and resulted in much less disturbance than if ground vehicles or horses had been used.

Road access to alpine ranges is limited, and the repeated use of sheep driveways is highly destructive. Because of the terrain, even trail construction is very expensive. A foot trail built to Forest Service specifications at the Carter Mountain site, which rises about 300 m in elevation in 2.9 km cost \$11,000 in 1964. It requires yearly maintenance.

A bulldozed road built for oil exploration purposes at the Carter Mountain site is a source of considerable erosion. Attempts to reseed the road

have been unsuccessful, and natural revegetation is almost nonexistent.

Griggs (1956) reported similar results on a road across alpine tundra in Colorado. Harrington (1946) attempted to revegetate the cutbanks along Trail Ridge Road in Rocky Mountain National Park with transplanted strips of alpine sod. Marr (1964) reported that after 25 years most of the sod strips were still separated by almost bare soil. Thus, the proper construction and maintenance of roads in alpine terrain challenge both the engineer and the ecologist.

New construction on the Beartooth Highway which traverses a large portion of alpine range along the Wyoming-Montana border is being contemplated (personal communication, Shoshone National Forest Staff). An opportunity for research into the revegetation of alpine range certainly exists there. However, a rock mulch might be a better way of directly protecting cutbank surfaces. Such a mulch would cause turbulence in the ground-level winds, and possibly increase the deposition of wind-borne soil particles and seeds. Determining the proper kinds and distribution of rock mulch surfaces to provide an esthetically pleasing vista would provide a challenge for landscape architects.

Some information is available on the use of herbicides to alter the composition of alpine vegetation. Smith and Alley (1966) tested 2,4-D and 2,4,5-T as possible control agents for *Geum rossii*. Both caused about a 98 percent reduction in *Geum*. The 2,4-D was recommended since it leaves less residual chemicals. In a followup study, Thilenius et al. (1974) found many other alpine forbs were also reduced by 2,4-D. Most important of these was *Trifolium parryi*, an important forage species. Grasses increased rapidly after treatment; the grass:forb ratio of the treated areas was 80:20, while that of untreated areas was 30:70. No change in total herbage was measured.

Because *Geum rossii* and *Trifolium parryi*, as well as other forbs, are important dietary items for sheep on alpine ranges (Strasia et al. 1970), and there was no increase in total herbage, such herbicide treatment does not appear to be a range improvement. An exception might be under a deferred grazing system where certain areas were reserved for late-season use. Since sheep tend to use more grass at this time (Strasia et al. 1970), an increase in the grass available to them might be beneficial. The deleterious effects of herbicides on the food supply and population density of pocket gophers has been previously mentioned.

The Colorado Division of Wildlife is studying alpine range fertilization as a method of improving the forage available to bighorn sheep (Yeager 1972). The rather negative responses of alpine ranges to fertilization reported in Scott and Billings (1964) have already been discussed. Bliss (1966) found

large amounts of nitrogen fertilizer would increase the productivity of alpine ranges in New Hampshire.

Billings and Mooney (1968) summarize the problem of increasing the productivity of alpine tundra through fertilization, and also provide a warning on possible ecological consequences. They stated, "The real problem in increasing tundra productivity is that most of the biomass increase is underground and not available for harvest by domestic animals or by any other means. Moreover, if one is to assume that most wild tundras are in a steady state over long periods of years, any method which tends to deplete these underground reserves is self-defeating since they are necessary to the survival of the producing plant themselves." More research is obviously needed to determine the effects of artificial perturbations on alpine ranges.

Many alpine ranges have been grazed by sheep for long periods of time, and these sheep return a great deal of organic matter and nutrients to the range in their feces. Because of the length of time some ranges have been grazed, there may have been some adaptation of the soil-plant nutrient cycle to this manuring. Cessation of use by sheep and consequent loss of the periodic addition of organic fertilizer could result in a change in plant growth. Whether this would be an increase or decrease is a matter of speculation, but it is a factor to be considered.

Large-scale weather modification may or may not improve alpine range. Cooper and Jolly (1969) state that the alpine zone is one of the most likely targets of weather modification, and that the ecological effects of weather modification are at present unknown.

Research on the impact of artificial winter precipitation enhancement (cloud seeding) on the alpine is being conducted in southwestern Colorado as part of the San Juan Ecology Project (Teller 1971). Similar research in southeastern Wyoming is known as the Medicine Bow Ecology Project (Knight 1975). A segment of that project was done in the alpine zone of the Medicine Bow Mountains of Wyoming by the Rocky Mountain Forest and Range Experiment Station (Thilenius 1975, Thilenius and Knight 1975). The objective was to provide baseline values on alpine vegetation and environment from which the ecological effects of snow increase might be measured.

Thilenius (1975) indicated large fluctuations in all subdivisions of standing crop (standing live vegetation, standing dead vegetation, litter, and total belowground standing crop) between sites and between the 2 years of study, and well-defined growth patterns could not be shown. Seasonlong average for the standing crop of live vegetation was 95.7 g/m, with over 50 percent produced by one species, *Geum rossii*. Standing crop of standing

dead vegetation and of litter were about three times greater than that of the live vegetation. Average belowground standing crop was 4999 g/m²; the percentage aboveground:belowground ratio was 10:90. The large fluctuations and different patterns of growth made it impossible to adequately determine baseline values of standing crop from which the possible effects of increased wintertime precipitation might be determined.

Integration with Other Uses

Watershed

Streamflow from the alpine is great in proportion to its area. Schwan and Costello (1951) estimated that although only about 3.5 percent of Colorado is in the alpine zone, the area produces approximately 20 percent of the State's runoff. Martinelli (1965) calculated a water yield potential at mid-June of over 1500 m³/ha, from a 112,000 ha alpine catchment on the Front Range of Colorado.

The alpine zone is, in general, an area of high precipitation. Although much of the precipitation that falls as snow may be transported by the prevalent high winds to lower elevations, much remains in the alpine even in the summer in persisting snowbanks. Melting snowbanks can prolong streamflow throughout the summer. Porous soils and loosely compacted surface rock also promote infiltration. The tendency of alpine plants toward a high degree of water economy limits evapotranspiration losses (Retzer 1962).

Marr (1964) speculated that large-scale hydrologic engineering was inevitable in much of the alpine zone of Colorado, because these alpine areas overlook a region of high urban density and agricultural activity, both of which make near-maximum use of water available from natural runoff and transmountain diversions. Mid- and late-summer runoff, the period of greatest deficiency, could be prolonged by holding more snow in the alpine where ablation is naturally slower due to cool temperatures. Marr further speculated that controlled melting of accumulated snow (establishment of artificial glaciers) was possible. These would allow snow falling in years of plenty to be held over for use in years of snow deficiency.

Martinelli (1966) listed several possibilities for increasing the alpine snowpack. These are: (1) weather modification, (2) intentional avalanching to store snow in high-elevation shaded valleys, (3) reshaping natural terrain features to improve their snow-trapping efficiency and capacity, (4) control of snowmelt by the addition of materials to the snow surface, and (5) snow fences or other artificial wind barriers to increase the amount of snow in

areas of natural accumulation, or to help shape terrain for more efficient snow storage.

All of these methods for increasing the alpine snowpack could certainly modify the alpine ecosystem and research is in progress on some of them: cloud seeding in the San Juan Mountains is operational, and snow fences were built in 1958 to increase the depth of natural snow in alpine areas of central Colorado (Martinelli 1966). Continued and intensive research is needed to define the ecological changes that might be brought about on the presently dynamic, but relatively stable, alpine ecosystems.

Some of the possibilities listed above could decrease the amount of range available for wildlife or domestic livestock by covering grazable alpine range with semi-permanent or permanent snowfields, and by increasing the moisture regime of areas adjacent to the snowfields to the point where they would be too wet to graze for most of the use season. Large artificial glaciers could affect the overall climatic regime, and possibly reduce the rather short growing season even more.

No great conflict is apparent between watershed management and **proper** range management. Because very little intensive management is practiced on wild alpine animals, proper range management, in this instance, refers to domestic sheep. Many of the alpine areas most suitable as alpine watersheds are really not suitable for grazing. These include (1) the steep sides of nivation cirques, talus slopes or rock glaciers, and exposed ridges, all of which produce little forage or have a high potential for erosion; and (2) the very wet areas below snowbanks or along alpine watercourses, which can be damaged by trampling or where the action of the sheep may cause increased siltation problems. Under proper management, such areas are excluded from use.

Wildlife

In the alpine zone, as in other types of rangelands in the western United States, range management and wildlife management are synonymous. Proper alpine range management must take into account the wild animal populations which also use the range. The question of competition between domestic and wild animals is often a matter of controversy and speculation. Because two or more species use a given range does not necessarily mean they are competitive.

The large wild animal usually considered characteristic of alpine ranges in the western United States is the bighorn sheep. The alpine zone provides much of its summer habitat, and in some localities these animals may occupy alpine range throughout the year. There is good evidence that this occupancy is forced (Smith 1954, Beuchner

1960, Moser 1962) and that, prior to intensive human-directed activity, bighorn sheep ranged through a wide variety of habitats including many at low elevations. Where possible, bighorns continue to use low-elevation habitats, especially during winter, and often yearlong (personal communication, Wildlife Staff Officer, Shoshone National Forest). Bighorn sheep are puzzling and unpredictable animals (Geist 1971). They are considered the "quality" trophy for big-game hunters in the United States (O'Connor 1973).

Bighorn sheep were apparently rather common through the Rocky Mountains in the early 19th century. A major decline in the latter part of that century has been blamed on scabies contracted from domestic sheep (Smith 1954, Beuchner 1960). Uncontrolled hunting and competition for space and forage with domestic livestock were other contributing factors.

The much improved hygiene of today's domestic sheep herds makes the likelihood of disease transmittal much less important, although it still is possible. Populations of bighorn sheep also appear to be naturally regulated by disease, principally a lung worm-pneumonia complex (Beuchner 1960). The crash population decline of the Tarryall herd in Colorado is a prime example of a sudden decline of a bighorn population due to a combination of this disease and over-solicitude in management. Beuchner (1960) lists many other areas where this kind of epizootic mortality occurred.

Beuchner (1960) states "the usurpation of alpine habitat by domestic sheep greatly reduced pristine numbers of bighorn sheep and continues to limit them." He also states that the detrimental influence of all classes of domestic livestock is greater on winter ranges than on the alpine summer ranges.

Experience on the Carter Mountain Alpine Research Area indicates bighorn sheep use the range mainly before and after the domestic sheep are present. Particularly attractive areas in early spring are the relatively level flats just above steep lava cliffs. These areas support a cushion plant community and are snowfree. The vegetation shows green foliage and flowers in May when most of the range is still dormant or snow covered. Bighorns have been observed on rough, rugged terrain below the range occupied by domestic sheep. These observations coincide with those of Beuchner (1960), who states that domestic sheep grazing in alpine areas force the bighorns into the more inaccessible and rugged terrain.

The fact that bighorns and domestic sheep do not appear to associate normally does not mean there is competition, or that removal of the domestic sheep from the alpine will cause a rise in the size of bighorn sheep populations as Beuchner seems to believe. Most sheep in the alpine are under a system

of herded grazing, and it may be the presence of the herder and his activities (especially shooting for predator control), equipment, horses, and dogs that are the real factors in the apparent segregation.

Personal observations in the Absaroka Mountains also inspected by Beuchner (1960) do not support his contention that "indisputable overuse of the vegetation" is present and due to domestic sheep grazing. He uses the presence of *Geum turbinatum* (*G. rossii*) as an indication of overuse, and indicates it is "virtually" unpalatable to domestic sheep. This statement is contradicted by the work of Strasia et al. (1970), which showed *Geum rossii* to be an important diet item of domestic sheep. *Geum rossii* is also abundant in areas of the Absaroka Mountains never grazed by domestic sheep, and while bighorns are present in these areas they are by no means abundant. Bighorns have been seen in close proximity to the unherded sheep band on the Carter Mountain Research Area.

There does seem to be direct competition for forage on lower elevation bighorn winter ranges where most of the forage has been removed by domestic livestock during the summer (personal communication, Wildlife Staff Officer, Shoshone National Forest).

Because of the importance of bighorn sheep as a quality trophy animal, it seems that an intensive study is needed to determine their relationship with domestic sheep using alpine range. Knowledge is lacking on the habitat preferences of bighorns on alpine range, their summer diet, and in areas where they are now forced to winter in the alpine, their entire winter ecology.

Little is known of the interrelationships of domestic sheep and other large ungulates using alpine range. Mountain goats may be more of a true alpine species than bighorns, but little is known of their activities. Mountain goats appear to prefer the steepest, most rugged terrain available. In contrast, bighorn sheep use this kind of terrain mainly for escape cover, and domestic sheep generally avoid it (Beuchner 1960). There appears to be nothing published on conflicts between domestic sheep and mountain goats, perhaps because their ranges do not often overlap.

Mountain goats have been transplanted into some areas of Colorado, Wyoming, and Montana which were outside their natural range. In these areas they tend to remain in the alpine zone throughout the year. Some concern has been expressed about the effects of this animal, both on the alpine vegetation itself and the possible conflict between mountain goats and bighorn sheep (personal communication, Region 2 Wildlife Management Staff Officer). Areas of particular concern are the Collegiate Range in central Colorado and the divide between the Sunlight Basin and North Fork of the

Shoshone River in northwestern Wyoming. Because these introductions are relatively recent, and on very rugged, inaccessible terrain, no really good information is available.

Both mule deer and elk use alpine range as summer habitat. Elk tend to use the cirque basins and alpine-subalpine ecotones to a greater extent than they do the more exposed areas. On the Carter Mountain Research Area, however, large numbers of elk antlers at elevations above 3350 m indicate a number of large bulls, at least, are on the alpine range in April or May (when antlers are shed).

Mule deer, especially large bucks, spend a great deal of time in the alpine zone of northwestern Wyoming, and have been seen on open, rolling alpine plateaus at elevations exceeding 3650 m. Beuchner (1960) indicates there is no evidence of forage competition between elk and/or mule deer and bighorns on alpine summer range, but feels there may be competition on winter ranges, particularly on those overpopulated with elk or mule deer.

The presence of pronghorn antelope on the alpine tundra of the Carter Mountain Research Area already has been described. All age classes of pronghorns have been seen, including does with kids. This use of alpine terrain by pronghorns is rather unusual, and their presence at about 3450 m elevation constituted a record for altitudinal distribution (personal communication with James Yoakum, BLM, Reno, Nevada).

Both black and grizzly bears are present in alpine tundra, but normally only in the summer (Pattie and Verbeek 1967). They may occasionally kill domestic sheep. Sheep herders will normally try to kill every bear they see. No information is available of bear predation on large, wild alpine animals. Grizzly bears may feed on microtines and ground squirrels.

The coyote and golden eagle are also present in the alpine, and are often accused of predation on both domestic and wild animals. The evidence is conflicting. Honess and Frost (1942), Smith (1954), Beuchner (1960), and Moser (1962) all indicate that coyotes and golden eagles are ineffective population control agents on bighorns. However, Rush (1940), Kennedy (1948), and Geist (1971) reported positive evidence of golden eagles attacking or killing bighorn lambs, and Brandborg (1955) related similar evidence of eagle predation on mountain goat kids. Because of their numbers and other habits, domestic sheep would seem to be more susceptible to predation by either of these animals, but good quantitative evidence is still lacking.

There are two viewpoints concerning the soil-disturbing activity of pocket gophers on alpine rangeland, both supported to a degree by research. One contends that pocket gophers have little effect,

because control results in no significant improvement (Ellison 1946, Ellison and Aldous 1952). The opposite viewpoint is that pocket gophers can be very detrimental to the range and should be controlled (Moore and Reid 1951). Most of the above work was carried out in subalpine areas. Whether any of the findings can be extrapolated to the true alpine is a matter of conjecture. It does appear that, under proper management, domestic sheep should be kept off areas severely disturbed by pocket gophers because the trampling action can only aggravate an already disturbed soil surface.

Recreation

The harsh environment (even in summer) and the general inaccessibility of the alpine zone makes it unsuitable for many common recreational activities. Nevertheless, many people find the alpine attractive. These may be only a small proportion of the total recreational population, but because of the general population increase, their absolute numbers have greatly increased, particularly in areas such as the Front Range of Colorado where the alpine zone is rather easy to reach, even by automobile.

Recreational use of the alpine zone is varied. It includes consumptive uses such as hunting and fishing, and also many nonconsumptive uses such as hiking, camping, mountain climbing, photography, and "nature watching." Skiing is not an important recreation in the alpine because of high winds, extreme cold, and a large amount of snowfree terrain. Many ski areas are located at the upper limits of subalpine zone. The alpine zone, however, does supply snow to these areas (fig. 14).

All direct human uses leave their impact, even "nature watching." Willard and Marr (1970, 1971) have investigated the effects of human activities on alpine tundra in Rocky Mountain National Park. The greatest damage takes place at areas near roads that present panoramic views of the alpine zone, and have been provided with parking lots for the convenience of sightseers.

The main damage is due to trampling, but rock collecting, flower picking, littering, and crushing of the tundra by vehicles also degrade the immediate alpine ecosystems. Both plants and soils are damaged, and effects can be measured only after a single season of human activity. With protection from trampling, the vegetation responds favorably, and the vegetative cover will increase some. Complete recovery will take many years at best.

The extent of snowmobiling in the alpine is not known. The harsh climate and difficulty of access may limit use. Some will inevitably be driven on alpine terrain, and their ecological impact should be determined.

Four-wheel drive vehicles, dune buggies, trail motorcycles, etc., are collectively known as ORV's (off-road vehicles). These are extremely popular for recreation in the western United States. The damage that may be done by a large number of ORV's on the tundra is well documented (Ives 1974), and in many States they are wisely banned from the alpine zone (fig. 15).

Although no quantitative studies have been made in alpine tundra, Bellamy et al. (1971) conducted controlled studies on very similar Arctic tundra to determine the influence of vehicles used for petroleum exploration. They concluded damage was proportional to: the number of times a vehicle



Figure 14.—Deep snowdrifts in the subalpine forest zone formed from snow blowing off alpine tundra, Medicine Bow Mountains, Wyoming.

Figure 15.—Tracks across alpine tundra in the Beartooth Mountains made by four-wheel-drive vehicles.



passes over a given location, the wetness of the site, the weight of the vehicles, and the kind of vehicles (vehicles with wide, flat tracks that conform to the ground surface were least damaging). They recommended further studies to determine the ecological impact of vehicular terrain disturbance and to investigate the processes of regeneration of vehicle tracks. All of the above statements can be applied to the alpine zone. If, as Bliss (1962) states, the alpine is a harsher ecosystem than the Arctic, the influence of uncontrolled vehicular travel and the slowness of regeneration may be even more pronounced.

Conflicts may exist between recreational use and livestock range use in some alpine areas. Burke (1969) points out that damage from grazing has a different meaning to the recreationist than to the range manager. To the latter, it means a decline in vegetation or soil. To the recreationist it means animal droppings on a trail or in a campground, muddy streams or other forms of water pollution, and unwelcome noise.

However, grazing or trampling by horses used for recreation purposes can also cause damage to critical areas. Since these are often near trails, camping spots, or major scenic attractions, they are often very evident. Burke (1969) believed that personally owned horses were more likely to cause such damage than those owned or operated by professional guides and outfitters, who work under a permit and graze their animals away from points of concentration whenever possible.

There is a great need for further research (ecological, sociological, and economic) on alpine recreation. It may be that the zone cannot withstand high concentrations of people, either under so-called "wilderness" conditions or more urbanized conditions.

Mining

One of the most evident human activities in the alpine zone is mining. Old supply roads, deserted structures, and mine tailings are a common feature in many areas of the Rocky Mountain West (fig. 16). The most evident visible alterations to the alpine landscape caused by current mining activities are the roads and exploratory excavations made by bulldozers. The problems related to roads and vehicles in the alpine apply even more to uncontrolled use of bulldozers. Roads for transportation or recreation often may be carefully designed and built to the best standards available. A "cat-road" built by a miner seeking a strike is not often so well constructed.

The problem is not confined to exploration. If a strike is made, subsequent development may also be detrimental. If the mine "proves out," structures and settling ponds are constructed and mine tailings accumulate. While the mine is in operation, attention may be paid to minimizing pollution and landscape damage, but when it is finally abandoned, the steps taken to limit pollution are no longer maintained and severe problems can occur.



Figure 16.—Severe disturbance of alpine tundra by surface mining operations. Beartooth Mountains, Montana.

SUMMARY AND CONCLUSIONS

Because the ecology of the alpine zone is unique, range management principles and practices developed in other ecosystems must be carefully considered before they are extrapolated into the alpine. Ecological features of the alpine zone that particularly influence or limit grazing by domestic animals are: thin atmosphere, cold temperature, erratic snow distribution, strong wind, rough terrain, and naturally unstable soils.

Alpine plants generally provide nutritious forage, but distribution and abundance may vary greatly between sites, and between years on a given site. Topographic location, degree and duration of winter snow cover, and wind exposure—all of which combine to influence the available moisture and temperature regime—are the key factors controlling plants on alpine ranges.

Sheep are the principal livestock in the alpine zone since normally available breeds of domestic cattle are poorly adapted to the cold and windy environment. Many alpine ranges have been used for grazing sheep since the mid 1800's. Prior to governmental control, sheep were herded in tightly grouped bands, continuously bedded in the same location for several nights in a row, and driven to and from water. These practices resulted in large

losses of forage through trampling, and in soil damage from excessive trailing.

Sheep must now be open herded and not allowed to remain in one area long enough to cause excessive forage utilization. Bedgrounds are used only for one night, and the sheep are slowly grazed to water, not driven. Ranges grazed under these conditions seldom show excessive use of forage or trampling damage. Deferred, rotation grazing systems are being used on some alpine ranges, and free-ranging sheep grazing is being studied on others.

Major problems in alpine range management are: lack of good indicators for determining range readiness, great difficulty in measuring forage utilization, inappropriate standards for determining alpine range condition and trend, and the long time-span needed to improve misused alpine ranges.

Alpine ranges are used for many other purposes besides grazing. They are the uppermost watersheds for the major western river systems, and important habitat for many wild animals, some of which (mountain goats, bighorn sheep, ptarmigan) spend a large portion of their life in the alpine zone. They have great recreational appeal, and the alpine zone usually comprises a significant proportion of the land within many western wilderness areas. Integrating alpine range management with these other uses is a major task for the resource manager.

LITERATURE CITED

- Alexander, A. F., and R. Jensen.
1959. Gross cardiac changes in cattle with high mountain (brisket) disease and in experimental cattle maintained at high altitudes. *Am. J. Vet. Res.* 20:680-689.
- Alexander, G.
1951. The occurrence of orthoptera at high altitudes with special reference to Colorado Acrididae. *Ecology* 32:104-112.
- Arnold, G. W.
1966a. The special senses in grazing animals I. Sight and dietary habits in sheep. *Aust. J. Agric. Res.* 17:521-529.
- Arnold, G. W.
1966b. The special senses in grazing animals II. Smell, taste, touch and dietary habits in sheep. *Aust. J. Agric. Res.* 17:531-542.
- Bamberg, S. A., and J. Major.
1968. Ecology of the vegetation and soils associated with calcareous parent materials in three alpine regions of Montana. *Ecol. Monogr.* 38:127-167.
- Bellamy, D., J. Radforth, and N. W. Radforth.
1971. Terrain, traffic and tundra. *Nature* 231:429-432.
- Benedict, J. B.
1970. Downslope soil movement in a Colorado alpine region: Rates, processes and climatic significance. *Arct. and Alp. Res.* 2:165-226.
- Beuchner, H. K.
1960. The bighorn sheep in the United States, its past, present, and future. *Wildl. Monogr.* 4, 174 p.
- Billings, W. D.
1969. Vegetational pattern near alpine timberline as affected by fire-snow drift interactions. *Vegetatio* 19:192-207.
- Billings, W. D., and L. C. Bliss.
1959. An alpine snowbank environment and its effects on vegetation, plant development, and productivity. *Ecology* 40:388-397.
- Billings, W. D., E. E. Clebsch, and H. A. Mooney.
1966. Photosynthesis and respiration rates of Rocky Mountain alpine plants under field conditions. *Am. Midl. Nat.* 75:34-44.
- Billings, W. D., and H. A. Mooney.
1968. The ecology of arctic and alpine plants. *Biol. Rev.* 43:481-529.
- Bliss, L. C.
1960. Transpiration rates of arctic and alpine shrubs. *Ecology* 41:386-389.
- Bliss, L. C.
1962. Adaptations of arctic and alpine plants to environmental conditions. *Arctic* 15:117-144.
- Bliss, L. C.
1963. Alpine plant communities of the Presidential Range, New Hampshire. *Ecology* 44:678-697.
- Bliss, L. C.
1966. Plant productivity in alpine microenvironments on Mt. Washington, New Hampshire. *Ecol. Monogr.* 36:125-155.
- Brandborg, S. M.
1955. Life history and management of the mountain goat in Idaho. *Idaho Dep. Fish and Game, Wildl. Bull.* 2, 142 p.
- Bray, J. R.
1962. The primary productivity of vegetation in central Minnesota, U.S.A., and its relationship to chlorophyll content and albedo. In *Die Stoffproduktion der Pflanzendecke*. p. 102-116. H. Leith, ed. Stuttgart, Germany.
- Burke, H. D.
1969. Wilderness engenders new management traditions. *Living Wilderness* 106:9-13.
- Caldwell, M. M.
1968. Solar ultraviolet radiation as an ecological factor for alpine plants. *Ecol. Monogr.* 38:243-268.
- Campbell, J.
1971. A study of the effect of weather modification on boreal toad populations in the San Juan Mountains. In *The San Juan Ecology Project, Interim Progress Report*, p. 222-241. H. Leo Teller, coord. Colo. State Univ., Fort Collins; Inst. Arct. and Alp. Res., Univ. Colo., Boulder; Dep. Biol. Sci., Fort Lewis Coll. Durango, Colo.
- Chabot, B. F., and W. D. Billings.
1972. Origins and ecology of the Sierran alpine flora and vegetation. *Ecol. Monogr.* 42:163-199.
- Choate, C. M., and J. R. Habeck.
1967. Alpine plant communities at Logan Pass, Glacier National Park. *Proc. Mont. Acad. Sci.* 27:36-54.
- Churchill, E. D., and H. C. Hanson.
1958. The concept of climax in arctic and alpine vegetation. *Bot. Rev.* 24:127-191.
- Cooper, C. F., and W. C. Jolly.
1969. Ecological effects of weather modification. A problem analysis. 160 p. Univ. Mich., Sch. Nat. Resour., Ann Arbor.
- Daubenmire, R. F.
1941. Some ecological features of the subterranean organs of alpine plants. *Ecology* 22:370-378.
- Duran, G. F., and H. F. Kaiser.
1972. Range management practices: Investment costs, 1970. U.S. Dep. Agric., Agric. Handb. 435, 38 p.

- Ellison, L.
1946. The pocket gopher in relation to soil erosion on mountain range. *Ecology* 27:101-114.
- Ellison, L., and C. M. Aldous.
1952. Influence of pocket gophers on vegetation of subalpine grassland in central Utah. *Ecology* 33:177-186.
- Faust, R. A., and T. J. Nimlos.
1968. Soil microorganisms and soil nitrogen of the Montana alpine. *Northwest Sci.* 42:101-107.
- Francis, Richard E., Richard S. Driscoll, and Jack N. Reppert.
1972. Loop-frequency as related to plant cover, herbage production, and plant density. USDA For. Serv. Res. Pap. RM-94, 8 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
- Franklin, J. F., and C. T. Dyrness.
1973. Natural vegetation of Washington and Oregon. USDA For. Serv. Gen. Tech. Rep. PNW-8, 417 p. Pac. Northwest For. and Range Exp. Stn., Portland, Ore.
- Geist, V.
1971. Mountain sheep. A study in behavior and evolution. 383 p. Univ. Chicago Press, Chicago and London.
- Golley, F. B.
1971. Energy values for ecological materials. *Ecology* 42:581-584.
- Gregg, R. E.
1947. Altitudinal indicators among the Formicidae. *Univ. Colo. Stud. Ser. D.* 2:385-403.
- Griggs, R. F.
1956. Competition and succession on a Rocky Mountain fellfield. *Ecology* 37:8-20.
- Hamilton, J. W.
1961. Native clovers and their chemical composition. *J. Range Manage.* 14:327-331.
- Harrington, H. D.
1946. Results of a seeding experiment at high altitudes in the Rocky Mountain National Park. *Ecology* 27:375-377.
- Hayward, C. L.
1952. Alpine biotic communities in the Uinta Mountains, Utah. *Ecol. Monogr.* 22:93-120.
- Holway, J. G., and R. T. Ward.
1965. Phenology of alpine plants in northern Colorado. *Ecology* 46:72-83.
- Honess, R. F., and N. M. Frost.
1942. A Wyoming bighorn sheep study. *Wyo. Game and Fish Dep. Bull.* 1, 127 p.
- Hutchings, S. S., and R. C. Holmgren.
1959. Interpretation of loop-frequency data as a measure of plant cover. *Ecology* 40:668-677.
- Ives, Jack D.
1974. Small scale examples: (2) The impact of motor vehicles on the tundra environment. In *Arctic and Alpine Environments*. p. 907-910. J. D. Ives and R. G. Berry, eds. Methuen.
- Jardine, J. T.
1912. Range improvement and improved methods of handling stock in National Forests. *Proc. Soc. Am. For.* 7:160-167.
- Johnson, P. L., and W. D. Billings.
1962. The alpine vegetation of the Beartooth Plateau in relation to cryopedogenic processes and patterns. *Ecol. Monogr.* 32:105-135.
- Johnson, W. M.
1962. Vegetation of high altitude ranges in Wyoming as related to use by game and domestic sheep. *Wyo. Agric. Exp. Stn. Bull.* 387, 31 p.
- Johnston, A., L. M. Bezeau, and S. Smoliak.
1968. Chemical composition and in vitro digestibility of alpine tundra plants. *J. Wildl. Manage.* 32:773-777.
- Jones, D. A., and R. Paddock.
1966. You can't turn 'em loose—or can you? *J. Range Manage.* 19:96-98.
- Kennedy, C. A.
1948. Golden eagle kills bighorn lamb. *J. Mammal.* 29:68-69.
- Klikoff, L. G.
1965. Microenvironmental influence on vegetation pattern near timberline in the central Sierra Nevada. *Ecol. Monogr.* 35:187-211.
- Knight, Dennis H., coord.
1975. The Medicine Bow ecology project, final report, February 28, 1975. 397 p. Univ. Wyo., Laramie, for Off. Atmos. Water Resour., Bur. Reclam., U.S. Dep. Int., Denver, Colo.
- Kuramoto, R. T., and L. C. Bliss.
1970. Ecology of subalpine meadows in the Olympic Mountains, Washington. *Ecol. Monogr.* 40:317-347.
- LaMonte, F.
1946. North American game fishes. 202 p. Doubleday & Co. Inc., Garden City, N.Y.
- Lewis, M. E.
1970. Alpine rangelands of the Uinta Mountains, Ashley and Wasatch National Forests. U.S. Dep. Agric., For. Serv., Reg. 4, 75 p. Ogden, Utah.
- Little, E. L.
1941. Alpine flora of San Francisco Mountain, Arizona. *Madrono* 6:65-81.
- Loope, L. L.
1969. Subalpine and alpine vegetation of north-eastern Nevada. Ph.D. Thesis, Duke Univ., Durham. 291 p.
- Marr, J. W.
1961. Ecosystems of the east slope of the Front Range in Colorado. *Univ. Colo. Stud. Ser. Biol.* 8, 134 p.
- Marr, J. W.
1964. Utilization of the Front Range tundra, Colorado. In *Grazing in terrestrial and marine environments*. p. 109-118. Blackwell Sci. Publ., Oxford.

- Martinelli, M., Jr.
1965. An estimate of summer runoff from alpine snowfields. *J. Soil Water Conserv.* 20:24-26.
- Martinelli, M., Jr.
1966. Possibilities of snowpack management in alpine areas. In *Forest hydrology*. p. 225-231. W. E. Sopper and H. W. Lull, eds. Pergamon Press, Oxford and New York.
- Mooney, H. A., and W. D. Billings.
1961. Comparative physiological ecology of arctic and alpine populations of *Oxyria digyna*. *Ecol. Monogr.* 31:1-29.
- Moore, A. W., and E. H. Reid.
1951. The Dalles pocket gopher and its influence on forage production of Oregon mountain meadows. *U.S. Dep. Agric., Circ.* 884, 36 p.
- Moser, C. A.
1962. The bighorn sheep of Colorado. *Colo. State Game and Fish Dep.* 49 p.
- O'Connor, J.
1973. The grand slam caper. *Outdoor Life* 151(1): 45-49.
- Osborn, W. S., Jr.
1958. Ecology of winter snow-free areas of the alpine tundra of Niwot Ridge, Boulder County, Colorado. Ph.D. Thesis, Univ. Colo., Boulder. 214 p.
- Paddock, M. W.
1966. The food habits of the pika *Ochotona princeps saxatilis* Bangs. M.S. Thesis, Univ. Colo., Boulder. 127 p.
- Parker, Kenneth W.
1954. A method for measuring trend in range condition on National Forest range, with supplemental instructions for measurement and observation of vigor, composition, and browse. 27 + 11 p. *U.S. Dep. Agric., Wash., D.C.*
- Pattie, D. L., and N. A. M. Verbeek.
1967. Alpine mammals of the Beartooth Mountains. *Northwest Sci.* 41:110-117.
- Paulsen, H. A., Jr.
1960. Plant cover and foliage use on alpine sheep ranges in the central Rocky Mountains. *Iowa State Coll. J. Sci.* 34:731-748.
- Pickford, G. D., and E. H. Reid.
1942. Basis for judging subalpine grassland ranges of Oregon and Washington. *Dep. Agric., Circ.* 655, 38 p.
- Rawes, M., and D. Welch.
1969. Upland productivity of vegetation and sheep at Moor House National Nature Reserve, Westmorland, England. *Oikos Supplementum* 11. Munksgaard-Copenhagen. 72 p.
- Retzer, J. L.
1962. Soil survey of Fraser alpine area, Colorado. *Soil Surv. Ser.* 1956 No. 20. 47 p. *U.S. Dep. Agric., For. Serv. and Soil Conserv. Serv., Colo. Agric. Exp. Stn., U.S. Gov. Print. Off.*
- Rodin, L. E., and N. I. Bazilevich.
1964. Biological productivity of the main types of vegetation in the Northern Hemisphere of the Old World. *Dokl. Akad. Nauk SSSR.* 157: 215-218.
- Rush, W. M.
1940. Bighorns need a break. *Outdoor Life* 84:38-40.
- Schwan, H. E., and D. F. Costello.
1951. The Rocky Mountain alpine type—range conditions, trends, and land use. (A preliminary report.) *U.S. Dep. Agric., For. Serv.* 18 p.
- Scott, D., and W. D. Billings.
1964. Effects of environmental factors on standing crop and productivity of an alpine tundra. *Ecol. Monogr.* 34:243-270.
- Smith, Dixie R.
1966. Pot test of nutritive status of two high elevation soils in Wyoming. *J. Range Manage.* 19:38-40.
- Smith, Dixie R.
1967. Gross energy values of above ground parts of alpine plants. *J. Range Manage.* 20:179-180.
- Smith, Dixie R.
1969a. Vegetation, soils and their interrelationships at timberline in the Medicine Bow Mountain, Wyoming. *Wyo. Agric. Exp. Stn. Sci. Monogr.* 17, 14 p.
- Smith, Dixie R.
1969b. In vitro digestibility of alpine forages in Wyoming. *USDA For. Serv. Res. Note RM-145*, 3 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
- Smith, Dixie R., and H. P. Alley.
1966. Chemical control of alpine avens. *J. Range Manage.* 19:376-378.
- Smith, Dixie R., and W. M. Johnson.
1965. Vegetation characteristics on a high altitude sheep range in Wyoming. *Wyo. Agric. Exp. Stn. Bull.* 430, 14 p.
- Smith, Dwight R.
1954. The bighorn sheep in Idaho, its status, life history, and management. *Idaho Dep. Fish and Game, Wildl. Bull.* 1, 154 p.
- Soil Survey Staff.
1970. Soil taxonomy of the National Cooperative Soil Survey. (Selected chapters from unedited text.) *U.S. Dep. Agric., Soil Conserv. Serv., Washington, D.C.* n.p.
- Stevens, D. R.
1966. Range relationships of elk and livestock, Crow Creek drainage, Montana. *J. Wildl. Manage.* 30:349-363.
- Stoddart, L. A., and A. D. Smith.
1955. Range management. 433 p. McGraw-Hill, New York.

- Stoecker, Robert, and Carl Bock.
1971. The effects of weather modification on animals in the alpine tundra. In The San Juan ecology project, interim progress report, December 1971. p. 193-219. H. Leo Teller, coord., Colo. State Univ., Fort Collins, for Off. Atmos. Water Resour., Bur. Reclam., U.S. Dep. Int., Denver, Colo.
- Strasia, C. A., M. Thorn, R. W. Rice, and D. R. Smith.
1970. Grazing habits, diet and performance of sheep on alpine ranges. J. Range Manage. 23:201-208.
- Strickler, G. S.
1961. Vegetation and soil condition changes on a subalpine grassland in eastern Oregon. USDA For. Serv. Res. Pap. PNW-40. 46 p.
- Taussig, W. H.
1962. An ecological study of *Formica neorufibaris gelida* Wheeler in the alpine tundra of Colorado. M.S. thesis, Univ. Colo. Boulder. 127 p.
- Teller, H. Leo, coord.
1971. The San Juan ecology project, interim progress report, December 1971. 401 p. Colo. State Univ., Fort Collins, for Off. Atmos. Water Resour., Bur. Reclam., U.S. Dep. Int., Denver, Colo.
- Thilenius, John F.
1975. Plant production of three high-elevation ecosystems. In The Medicine Bow ecology project, final report, February 28, 1975. p. 60-75. D. H. Knight, coord., Univ. Wyo., Laramie, for Div. Atmos. Water Resour. Manage., Bur. Reclam., U.S. Dep. Int., Denver, Colo.
- Thilenius, John, and Dennis Knight.
1975. Snow duration and growing season microclimate in alpine tundra and subalpine meadows. In The Medicine Bow ecology project, final report, February 28, 1975. p. 23-37. D. H. Knight, coord., Univ. Wyo., Laramie, for Div. Atmos. Water Resour. Manage., Bur. Reclam., U.S. Dep. Int., Denver, Colo.
- Thilenius, John F., and Dixie R. Smith.
[In press.] Vegetation and soils of an alpine range in the Absaroka Mountains, Wyoming. USDA For. Serv. Res. Pap. RM-
- Thilenius, John F., Dixie R. Smith, and Gary R. Brown.
1974. Effect of 2,4-D on composition and production of an alpine plant community in Wyoming. J. Range Manage. 27(4):140-142.
- Tietjen, H. P., C. H. Halvorson, P. L. Hegdal, and A. M. Johnson.
1967. Gopher relationships, Black Mesa, Colorado. Ecology 45:634-643.
- U.S. Department of Agriculture, Forest Service.
1968a. Forest Service Manual—Range management. Section 2223.62—Sheep distribution. n.p. Wash., D.C.
- U.S. Department of Agriculture, Forest Service.
1968b. Range environmental analysis handbook. Rocky Mountain Region (R-2). Forest Service Manual 2209.21. n.p. Denver, Colo.
- Warren Wilson, J.
1957. Observations on the temperatures of arctic plants and their environment. J. Ecol. 45:499-531.
- Wasser, C. H., and J. L. Retzer.
1966. Ecology and utility of the central Rocky Mountain alpine zone. In Int. Grassl. Congr. Proc. 9, 357-361.
- Wentworth, E. N.
1948. America's sheep trails. Iowa State Coll. Press. Ames. 667 p.
- Willard, B. E.
1960. The ecology and phytosociology of the tundra curves, Trail Ridge, Colorado. M.S. thesis, Univ. Colo., Boulder. 144 p.
- Willard, B. E.
1963. Phytosociology of the alpine tundra of Trail Ridge, Rocky Mountain National Park, Colorado. Ph.D. thesis, Univ. Colo., Boulder. 243 p.
- Willard, B. E., and J. W. Marr.
1970. Effects of human activities on alpine tundra ecosystems in Rocky Mountain National Park, Colorado. Biol. Conserv. 2:257-265.
- Willard, B. E., and J. W. Marr.
1971. Recovery of alpine tundra under protection after damage by human activities in the Rocky Mountains of Colorado. Biol. Conserv. 3:181-190.
- Yeager, L. E., ed.
1972. Colorado game research review 1970-1971. Game Res. Sect., Colo. Div. Game, Fish and Parks. Fort Collins, Colo. 49 p.

Thilenius, John F.

1975. Alpine range management in the western United States—principles, practices, and problems: The status of our knowledge. USDA For. Serv. Res. Pap. RM-157, 32 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521

Reviews the present knowledge on the ecology and management of the alpine zone in western North America; describes the characteristics of the alpine; covers the unique ecology of the high-elevation, cold-dominated, alpine ecosystems; and discusses their management, with emphasis on the range resource and its relationship with other uses.

Keywords: Alpine ecosystem, alpine range management.

Thilenius, John F.

1975. Alpine range management in the western United States—principles, practices, and problems: The status of our knowledge. USDA For. Serv. Res. Pap. RM-157, 32 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521

Reviews the present knowledge on the ecology and management of the alpine zone in western North America; describes the characteristics of the alpine; covers the unique ecology of the high-elevation, cold-dominated, alpine ecosystems; and discusses their management, with emphasis on the range resource and its relationship with other uses.

Keywords: Alpine ecosystem, alpine range management.

Thilenius, John F.

1975. Alpine range management in the western United States—principles, practices, and problems: The status of our knowledge. USDA For. Serv. Res. Pap. RM-157, 32 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521

Reviews the present knowledge on the ecology and management of the alpine zone in western North America; describes the characteristics of the alpine; covers the unique ecology of the high-elevation, cold-dominated, alpine ecosystems; and discusses their management, with emphasis on the range resource and its relationship with other uses.

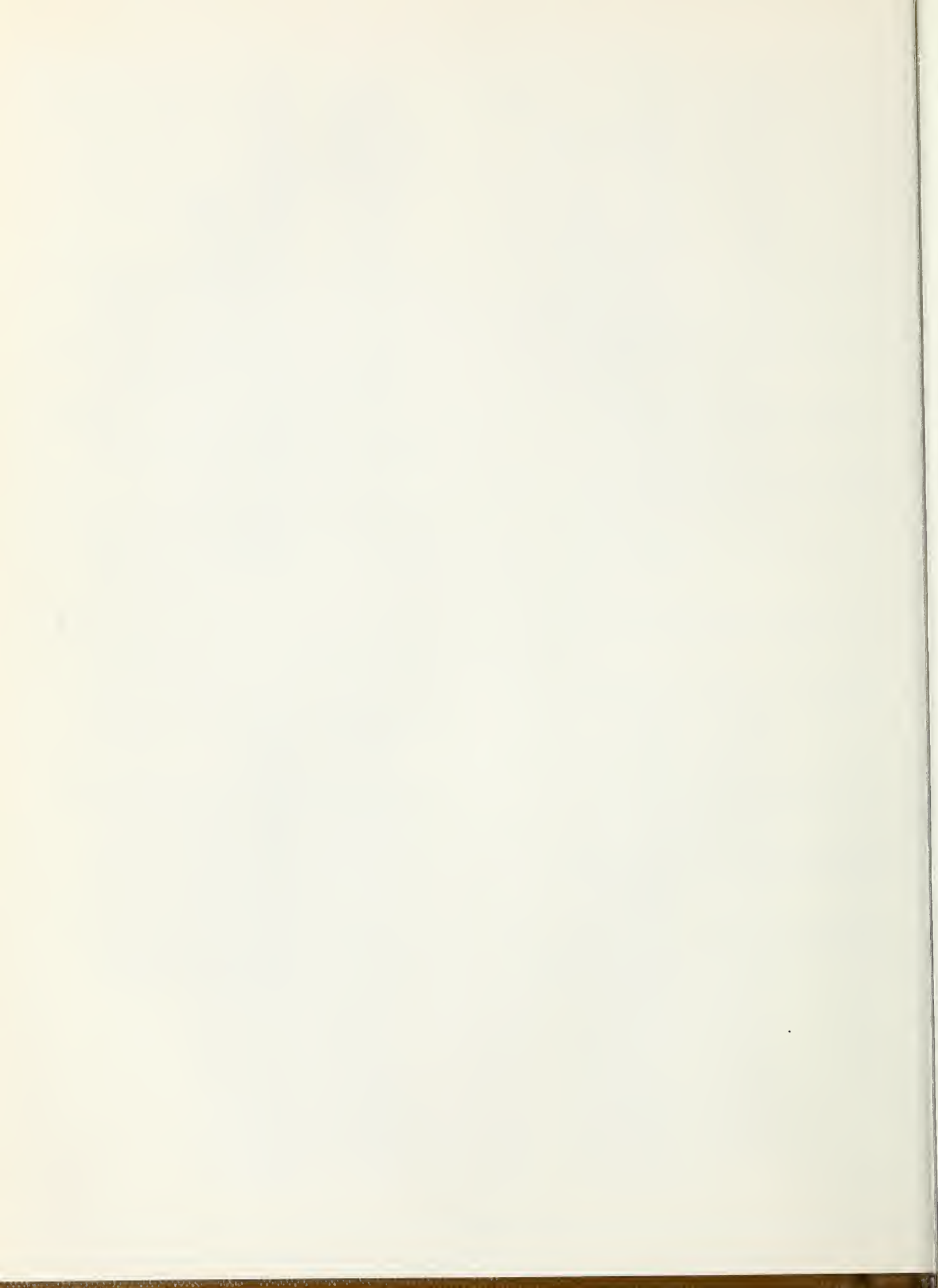
Keywords: Alpine ecosystem, alpine range management.

Thilenius, John F.

1975. Alpine range management in the western United States—principles, practices, and problems: The status of our knowledge. USDA For. Serv. Res. Pap. RM-157, 32 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521

Reviews the present knowledge on the ecology and management of the alpine zone in western North America; describes the characteristics of the alpine; covers the unique ecology of the high-elevation, cold-dominated, alpine ecosystems; and discusses their management, with emphasis on the range resource and its relationship with other uses.

Keywords: Alpine ecosystem, alpine range management.



Although this report discusses research involving pesticides, such research does not imply that the pesticide has been registered or recommended for the use studied. Registration is necessary before any pesticide can be recom-



Use Pesticides Safely
FOLLOW THE LABEL
U.S. DEPARTMENT OF AGRICULTURE

mended. If not handled or applied properly, pesticides can be injurious to humans, domestic animals, desirable plants, fish, and wildlife. Always **read** and **follow** the directions on the pesticide container.

The use of trade and company names is for the benefit of the reader; such use does not constitute an official endorsement or approval of any service or product by the U.S. Department of Agriculture to the exclusion of others that may be suitable.

